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The Cover: Glass-bulb mercury-arc traction rectifiers at one of the substations of the British Columbia Electric Railway Company, Vancouver, may be inspected during the forthcoming AIEE Pacific Coast convention, to be held at Vancouver, September 9–11, 1942.

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HIGH LIGHTS . . .

Protection Against Lightning. Data on properties of natural lightning have been obtained by observing damage by lightning strokes to thin metal surfaces and evaluating from laboratory tests the characteristics of the lightning causing the damage (*Transactions pages 559–64*). Analysis of abnormal currents in distribution transformers has shown that under certain conditions of direct stroke, excessive currents may wreck the secondary windings; long-duration surges or shorter repeated surges saturate the transformer cores, producing greatly increased surge currents in the primary windings (*Transactions pages 564–8*). In installing buried counterpoise for lightning protection of transmission lines, installation of an arbitrary length of conductor at each location and estimating the additional amount required from measurement of the ground resistance of the trial location have been found to be a more practical procedure than striving for the values of footing resistance indicated by the accepted formulas (*Transactions pages 599–603*). Developments in testing technique for lightning arresters have resulted in a high-voltage cathode-ray oscillograph of the cold-cathode type with the film in the evacuated chamber (*Transactions pages 549–53*) and simplified methods of calculating approximately the impulse-generator circuit constants required to produce specified waves (*Transactions pages 539–44*).

Ignitron Rectifiers. Sealed ignitron tube rectifiers, ranging in capacity from 75 to 400 kw per unit, with d-c output potentials of 250 to 600 volts, have been installed to supply d-c power for various types of industrial loads (*Transactions pages 594–9*). For excitation of ignitron rectifiers, static magnetic-impulse circuits have been preferred in many cases; ignitor requirements and tests for measuring excitation-circuit capacity have been described for three such circuits (*Transactions pages 574–7*). Basic analytical methods have been developed to aid in establishing load-cycle ratings of ignitron rectifiers, by applying a general method applicable to various types of apparatus to specific conditions encountered in ignitrons (*Transactions pages 545–8*).

Rating Electric Apparatus. A review of the ambient-temperature values now used for rating electric apparatus has indicated the desirability of clarification in methods. For apparatus rated on the basis of an ambient of 40 degrees centigrade, appreciable margins in permissible temperature rise have been found to exist under many conditions (*Transactions pages 553–8*). Since electronic devices are used extensively with intermittent loads, such loads have been especially considered in the assignment of ratings for these devices, and methods of rating that seem to be generally applicable to many tubes and tube arrangements have been suggested (*Transactions pages 569–73*).

The Engineer, the War, and the Peace. The engineering genius that has developed under democracy will provide our armed forces with the weapons they need—"enough and on time," a prominent engineering educator declares (*pages 402–04*). Not only are we now fighting an engineers' war, but engineers are already drawing the blueprints by which the army now fighting a war in factory and field will be converted to winning peace and prosperity, according to Retiring AIEE President Prince (*pages 393–6*).

D-C Moving-Magnet Instrument. A d-c instrument developed as a battery-testing voltmeter has characteristics, obtained by the use of new permanent-magnet materials, that make it an acceptable substitute for a permanent-magnet moving-coil instrument of normal sensitivity (*Transactions pages 586–8*).

Uses of the Carbon Arc. The carbon arc, a versatile source of both visible and invisible radiation, is adapted to various types of commercial and industrial operation, including processes which require specific bands of ultraviolet radiation or close reproduction of the effects of natural sunlight, and applications necessitating a light source of small area and extreme brilliance (*Transactions pages 581–5*).

Fluorescent-Lamp Electronics. Of the two energy converters connected in series, which constitute the fluorescent lamp, the first, a gaseous conductor that converts electric energy into ultraviolet radiant energy, is an electronic device; the second is the coating of fluorescent powder that acts as a frequency changer to convert ultraviolet radiation into visible light (*Transactions pages 607–12*).

Impregnated-Paper Insulation. Most recent of a series of studies of the breakdown strength of impregnated paper shows a marked decrease of dielectric strength with increasing paper density; results also showed the dielectric strength to be higher when the paper is impregnated with thin rather than heavy oil (*Transactions pages 618–22*).

Correction. Price of the June 1942 Supplement to Electrical Engineering—Transactions Section, now available, was incorrectly stated in the July 1942 issue of *Electrical Engineering* (page 360) as $1 outside the United States and United States possessions. The price is 50 cents per copy to Canada and other countries as well as the United States and its possessions.

Electric Control of Locomotive Boiler. On steam boilers of electric and Diesel-electric locomotives, the electric controls needed for efficient, safe, and uninterrupted operation may be automatic or semiautomatic; some are required by operating necessities and others by safety regulations (*Transactions pages 604–06*).

Rectifiers for Telephone Offices. Various types of thyratron-tube self-regulating rectifiers are described in this issue, including two types which by electronic means control the output current of thyratron rectifiers by the voltage applied to the grids to regulate the output voltage (*Transactions pages 613–17*).

A Look at Engineering Education. A canvass among engineering educators and employers of engineering graduates revealed some interesting opinions on the objectives of engineering education—what they are or what they should be; these are surveyed as a basis for reformulating educational aims to serve a changing society (*pages 406–14*).

Rectangular Tubular Conductors. Formulas have been derived from which can be calculated the short-circuit stresses in the supports of single-phase or polyphase a-c or d-c busses made up of identical strap or rectangular tubular conductors with parallel coplanar axes (*Transactions pages 578–80*).

Sleet on Electrified Railroads. Electrified railroads operating with overhead contact systems have ice-storm problems similar to those confronting power companies, and a number of special problems peculiar to the railroads (*Transactions pages 589–93*).

Lamme Medal. Presentation of the 14th AIEE Lamme Medal during the summer convention at Chicago provided the occasion for inspiring surveys of the careers of both the founder and the 1941 recipient, Forrest E. Ricketts (*pages 396–401*).

Summer Convention. For the benefit of the Institute members who could not be present in person, the Institute Activities section of this issue is largely devoted to a "summer convention in type" (*pages 417–32*).

Coming Soon. Among special articles currently in preparation for early publication in *Electrical Engineering* are: an article on quality control in connection with war production by Lieutenant Colonel L. E. Simon; an article on powder metallurgy by F. C. Kelley; an article discussing various aspects of the electromagnetic field by Leigh Page; an article on the engineer and the engineering method by A. R. Gruehr (M'30); an article describing the training provided in a modern technical high school by C. E. Crofoet (M'28).

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The Engineer's Last in the Postwar World

DAVID C. PRINCE
PRESIDENT AIEE, 1941–42

The engineer's last, to which he must stick if he is to make the maximum contribution to the postwar world, is defined by Retiring President Prince as working out the plans for a peacetime production of goods and services comparable to our wartime production, which would provide "not merely sustenance and military protection, but comfort and security for our entire population."

APPELLES, the court painter to Philip of Macedon, was exhibiting one of his portraits. A shoemaker criticized him for representing a shoe with one latchet too few, and Appelles corrected the error. The shoemaker was delighted at having his advice accepted and added a criticism of the manner in which the leg was painted. But this was too much for Appelles, who broke out, "Let not the shoemaker judge above his shoe."

The engineer of today is in much the same position as this shoemaker. The shoemaker's advice was taken once. The engineer's advice has been taken many times. The war which we are now fighting is an engineer's war.

When this war is over the engineer will have a large part in the attempt to construct a peace free from the faults of the peace made at Versailles; but like the shoemaker of old—400 B.C.—he must stick to his last. He is the man who understands all the processes from mining through design and manufacture to application of a finished product. He is the man who knows how to build a Grand Coulee dam by attention to details that range from the sample borings for the foundations to the feeding and housing of the workmen. He is one of the specialists of our civilization, but like any specialist he has his limitations. He must keep from overreaching himself, as the shoemaker did, by seeing just what his most valuable contribution to our postwar world can be.

The material resources of the United States and our knowledge of production are enabling us to make $60 billion worth of products for war this year, in addition to what we need to keep alive—to produce, in fact, a total of $115 billion worth. We could produce a comparable amount of goods and services in a peace year, and that would provide not merely sustenance and military protection, but comfort and security for our entire population. Working out the plans for this job is our engineer's last.

The broad features of the problem must be seen first. Our productive resources in men and machines must be ascertained. The war-production picture is known. It can be presented in as much detail as necessary. The outline of a peace program that we should like to create, and can create, after the war—this can be seen in the same way. It can be worked out in as much detail as is necessary at this time.

The picture of war production is the picture of an existing reality; but the picture of peace production is not. To make it real we must solve the problem of reconversion after the war is over. If we do not bridge the gap between war and peace, we may have from 25 to 30 million people unemployed for an indeterminate time.

At present a record number of people are being employed at high wages. They will have money to spend when the restrictions upon spending are lifted, and they have desires to buy things—desires that existed long before the war. This combination of the power to spend and the desire to spend can create an era of plenty.

To an economist it is a truism that purchasing power and production are equal. It is not true, however, that those goods the production of which creates purchasing power will automatically be bought by that purchasing power. The accommodation of production to purchasing power must be planned, and the planning is a job requiring engineering methods. It is a job for many engineers, not for just one, or even a few.

Essential substance of president's address delivered at the annual meeting during the AIEE summer convention, Chicago, Ill., June 22–26, 1942.

David C. Prince, is vice-president in charge of application engineering, General Electric Company, Schenectady, N. Y.

Full employment after the war will make possible a total production of $110 billion in terms of 1940 dollars. At the present ratio of wages to prices, wages and salaries will amount to about $68 billion, which with the incomes of farmers and professional people will produce a consumer market of $77 billion.

Much of this market, of course, will not be affected by the transition from war to peace. Soldiers, when they become civilians again, will eat the same kinds of food that they eat now, and their clothes will be made of the same materials. Aluminum and steel sheets are the same for war or peace. Automobiles, refrigerators, and radios, however, are at present out of production, and from nine months to a year will be required to get them back into production, even if reconversion is well planned. If it is badly planned, the time will be much longer.

Again, if the reconversion is well planned, automobiles, refrigerators, and radios will appear in about the right proportion. If the planning is poor, there will be too many automobiles and too few refrigerators. This is dislocation of industry, and unemployment is the result. The purchasing power of displaced employees falls; with it the demand as a whole falls further; then more men are thrown out of work, and so on. The effect is cumulative. Yet this trouble can be avoided if the engineers of our industrial concerns will undertake the problem, first of apportioning production, then of planning the details of conversion, in such a way as to produce the desired volume of production.

The engineers of raw and semifinished materials will gear their production to the requirements of those making the finished product, as will the makers of tools. Power-company engineers will survey the power needs of industry and have the kilowatts ready.

Some of the smaller manufacturing companies do not possess the technical staffs required to convert their plants from peace to war. As a result, they are suffering from a lack of war orders which no amount of political pressure can remedy. When the time comes for reconversion, they will be even worse off. These small concerns will find their prewar products outmoded by war developments. They will not know what to make, or how to make it.

This is an opportunity for the consulting engineers. They can determine first which products are scarce, and which are too abundant. Then they can survey the field to see what locations are best adapted to produce those goods of which more is needed. Lastly they can design up-to-date, efficient factories to make their clients better able to compete with the firms which progressed during the war.

The opinion has been expressed that the postwar era will be one of intense competition. It is to be hoped that this will be true, but in a healthy sense—that each producer will be competing to achieve the highest efficiency, to pay the highest wages, and still to deliver the lowest-cost product. Unhealthy competition will result if too many producers crowd into a small section of the market, competing for survival where there is not enough purchasing power to go around. Yet the fact that total purchasing power must be equal to total production shows that there must be a market for all if the production is correctly apportioned.

The factories that will require consulting aid include those now making explosives and other things having either no peacetime uses, or greatly reduced peacetime uses. It is to be hoped that these plants can be kept in running order to be ready for another war, should one come. There is no better insurance against the next war. Some of these plants are located apart from the existing towns and have been created new with all their homes and services. New industries suitable for these communities should be found. Excellent organizations and the general services, such as light, heat, water, sanitary and even recreational facilities, are already in existence in the new towns. Opportunities exist to use them to keep the population available for future war production.

Much has been said of public works as a flywheel for business. But the engineer, sticking to his last, is trying to avoid those business fluctuations that require a flywheel, and regards public works as merely one kind among all the kinds of things required by the community. The constructional features of public works, and their planning, are right down his alley. Every community has so many factories or mercantile establishments to serve the neighboring farms. These require services in the form of water sewers, streets, parks, schools, hospitals, and residential areas. All of these should be scientifically proportioned, and plans for them made ready to carry out. The volume of such projects released in any year should be such as to keep a building industry of reasonable size occupied. Many kinds of engineers will work upon phases of this problem.

The prosperity of any community depends upon a reasonable balance within its market area. A nation must have enough exports to pay for its imports. If it has too few exports in comparison to imports, it goes broke If it has too many, it has to give the surplus away. Similar situations confront regions or towns. For every community the problem is whether it is putting its productive activities to the best possible use. The task of the engineers in every community is to work together in surveying this problem, and finding solutions for it.

Emporia, Kans., for instance, has suffered a decrease in population because it has few industries, and no war industries. Has the drift of people away from Emporia gone as far as it will? Do the citizens of Emporia want it to remain an agricultural marketing center and college town?

Wichita, Kans., is a boom aviation town. Present estimates indicate that its postwar commercial-aviation

manufacturing will be about one fourth the present volume. How much of the permanent aviation manufacturing business is Wichita's share, and what is the most profitable activity for those left over? San Diego, Calif., is like Wichita, with the naval base added in for good measure. Neither is a source of raw materials, except farm products.

Seattle, Wash., however, is in the heart of the timber country. It is in a region of recurrent showers, which do not favor the aircraft industry. Yet, if plastic bonded plywood is to make the civilian airplane of the future, Seattle is better adapted than either Wichita or San Diego to maintain an aviation industry.

In California and in Texas natural gas is plentiful. Neither of these states yet has the industrial development to make full use of this cheap source of power, although some progress has been made during the war.

Detroit, Mich., has seen large factories built to make tanks and other war material. These are outside the city limits and call for general rearrangement of transportation and residential areas.

The future well-being of the United States demands that engineers work out solutions to these problems, with full employment of the local labor force as the central objective. In our war effort we are learning that the only real limitation to production volume is the available labor force.

The solution of a local industrial problem is never complete or independent of problems elsewhere. The suburbs of a city must be considered with the city. The division of the country into Federal Reserve districts is a realization that it consists of marketing regions, each of which is an organic whole of interdependent parts. Many statistics are kept on a Reserve District basis. The industries in one of these districts are interrelated. Therefore, local engineering councils logically should send representatives periodically to Reserve District conventions, there to thresh out problems which involve more than one town or city.

There will still be national problems left to be treated by a national representative gathering. All this planning, however, should have a "grass roots" foundation. The local people must first make up their minds as to what their locality requires. The local plans can then be freed from their conflicts by representatives of Federal Reserve or other logical areas and finally the national total can be cast up. In that way we can have the maximum amount of local freedom of initiative, and at the same time some assurance that the parts will add up to a total of full employment and output.

The solution of all these problems is the engineer's last. Perhaps AIEE members will say, "Good Lord! We are only electrical engineers. You can't expect us to know much about things like making airplanes out of plywood." Yet remember that there are many, many different kinds of engineers to solve these different problems. In trying to make up programs for AIEE conventions—gatherings of electrical engineers only—one is impressed by the variety of subjects necessary to keep *our* membership interested. The American Society of Mechanical Engineers has many more divisions than we and the total list of engineering societies is constantly growing. Each society is responsible for part of the shoe, so to speak, and all must work together if the complete job is to be done.

How does the engineer make his shoe fit the last? He must work with the facts. Market surveys to determine the size of demand consist of observation of purchase habits and the densities of population. Mining is directed by test drilling. Circuit breakers, iron plate—materials of all kinds are made and tested in accordance with specifications. Designs are made to accomplish specific results, and it is a matter of test and measurement whether the proper results are achieved. We deal in theories, but they must be demonstrable. If they are not, they become mere speculations, and have no more meaning to us than theories about the number of angels that can stand on the point of a needle.

Again, in making his shoe, the engineer is resolved that whatever he does must have some practical and useful effect. Some scientist may be content to study the movement of the stars in their courses. He may be able to predict an eclipse—yet the eclipse will occur, even if he does not predict it and knows nothing about it. What's more, nothing he does can stop it. His occupation is purely a search for knowledge. The engineer must have action. His knowledge must be the means to an end which lies within his power to accomplish. He may acquire knowledge of astronomy, as our scientist does, but he intends to use it immediately, for example in navigation. If he observes rainfall, it is to provide a spillway big enough to carry it off, or a power plant to produce a determined amount of firm, or peak, power. The factory that he plans is to be built to make some product at a cost that has been calculated beforehand.

The engineer is not required to have even an opinion as to whether our postwar world will be totalitarian or democratic, communistic or capitalistic There will be much the same things for him to do in any of these possible worlds; for his world is governed by physical laws, or by economic laws, or by the laws of human nature. If he feels that our free-enterprise system is best, his strongest argument is to make it work superlatively well.

Industry is carrying on now, breaking records in war production every day in spite of a barrage of irrelevant criticism and miles of red tape. Was it right, for example, to secure patent rights to German processes for hard cutting materials and synthetic rubber? Such questions only distract engineers from present problems of production. They may be likened to the razzing of the spectators at a baseball game. The engineers must stick to their business—their last.

In making his shoe the engineer does not worry about

what *may* happen so much as about what *can* happen. If he builds a bridge, he knows that it *may* be blown up by enemy bombs or that it *may* become useless because the main highway over it has been rerouted. But he knows that it *can* carry the load which it ought to carry, and he builds the bridge. A project economically sound may be rendered unsound by changes in the laws, in tariff rates, in the rate of interest, or by a revolutionary new invention, but these further considerations are the concern of someone else. The engineer acts on the basis of present facts. For the future he must act, to some extent, on the basis of assumed facts. Then, of course, his actions are tentative; the findings are qualified by facts to be ascertained later. But all the things that *may* happen, the considerations that lie beyond the field of knowledge of some particular engineer, are to that engineer as the leg which Appelles had painted was to the simple shoemaker. We must let Appelles worry about the leg.

The engineer's job takes time. Surveys cannot be made overnight. Designs take time. Construction plans take time. Tooling takes time, as we all know from our experience in converting our factories to war production. The plans for conversion from war to peace must be begun soon enough for plants to be ready to receive soldiers and sailors home from the war, to receive industrial workers no longer needed in powder mills and tank factories. The time factor must be reckoned in the equation. It is part of the last.

Engineers make designs and plan production of war material undeterred by questions of who will win, or when. They close their ears to the attacks of politicians or fifth columnists. They refuse to get drunk either on the defeats or on the victories. Production must go on at a steadily increasing pace.

The war will be over some day. The engineer does not know when. He does know that some day he will have to turn the army now fighting a war in the factory and in the field to winning peace and prosperity. He is already drawing the blueprints for that conversion. This is not inconsistent with the war effort; for the war job and the peace job are the two halves of the one big job that faces us all.

Every one of us has a shoe to make, and a last to make it by. Let us stick to our lasts.

Forrest E. Ricketts—1941 Lamme Medalist

AWARDED annually for "meritorious achievement in the development of electrical apparatus or machinery," the AIEE Lamme Medal was conferred for 1941 upon Forrest Eugene Ricketts (A'16), vice-president of the Consolidated Gas Electric Light and Power Company, Baltimore, Md., at the recent AIEE summer convention at Chicago, Ill.

The presentation ceremonies were opened by C. A. Powel (F'41) for the Lamme Medal committee, who said, in part:

"This annual recognition of outstanding work was made possible by a bequest made by the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company, to provide for the award by the Institute of a gold medal, the recipient being selected by a committee of nine members.

"Benjamin Garver Lamme was born near Springfield, Ohio, in 1864. He grew up on a farm, received his early education in the country schools, and went from there to Ohio State University, from which he was graduated in 1888 with a degree of mechanical engineer. Early the following year he entered the service of the Westinghouse company at Pittsburgh, and a few months later began his career as a designer of electric machinery. His success in this field was phenomenal, covering as it did pioneer work in d-c generators and d-c railway motors, single and polyphase a-c generators, turbogenerators, synchronous converters, induction motors, and single-phase railway motors, on all of which his engineering skill left a permanent mark.

"Mr. Lamme was recognized as the outstanding electrical designer of the Westinghouse company almost from the time he began his work, and was chief engineer of the company for many years prior to his death in 1924. His technical papers, some of which have become classics, are remarkable examples of the presentation of technical matter in clear, understandable, nonmathematical language.

"In spite of his modest and retiring disposition, which caused him to shun publicity, his ability was widely recognized and he was awarded the Edison Medal in 1918 for 'invention and development of electrical machinery.' He also received the first award of the Joseph Sullivant Medal, which is awarded at five-year intervals by Ohio State University to the alumnus who has made the most notable contributions to 'the liberal, the fine, or the mechanic arts.' He was a member of the Naval Consulting Board during World War I.

"On the obverse of the Institute's Lamme Medal, accompanying the portrait of the donor, are the words: 'The engineer views hopefully the hitherto unattainable.' These words are taken from one of Mr. Lamme's ar-

ticles and are all the more appropriate in that they aptly characterize his own attitude.

"The reverse of the medal represents Niagara, the birthplace of large scale hydroelectric power, where are installed the great electric generators which Lamme designed. In the background is a modern industrial city, symbolic of the new civilization made possible by electric power."

AIEE Lamme Medal

The achievements of the medalist were described by Nicholas Stahl (F'13) chief engineer, Pennsylvania Power and Light Company, Allentown, and the medal was presented by President David C. Prince. Essential substance of Mr. Stahl's address and Medalist Ricketts' response follows.

Career of the Medalist

NICHOLAS STAHL, Fellow AIEE

Benjamin Garver Lamme *is* a great engineer. The present tense is used with intention, because, whatever one's belief in immortality, there can be no doubt that his spirit lives with us in the bequest of his substance and the inspiration of his mind. So well expressed by the Lamme Medalist of 1938, Marion A. Savage, who said, "All engineers who have to design electrical machinery honor the name of Benjamin G. Lamme, who did so much to advance the designing art. It was my good fortune to know Mr. Lamme personally. His kindly nature, remarkable memory, and keen mind were an inspiration to a young engineer."

A sidelight on the character of Mr. Lamme, out of my own experience, is a clear index of the way the mind of the man approached any problem, no matter how trivial, with the viewpoint of an engineer. One night, many years ago, Mr. Lamme, Norman A. Storer, the Lamme Medalist of 1939, and I were returning from New York to Pittsburgh and, for exercise, were walking to the station. This was before anyone had much more than dreamed of air conditioning. As we passed a candy shop, Mr. Lamme suddenly darted in and in a moment or two returned with a little brown paper bag.

Mr. Storer said, "Why Mr. Lamme, I didn't know you were so fond of candy," to which Mr. Lamme replied, "I'm not. I never eat it."

"Then why the bag?" said Mr. Storer.

Mr. Lamme rejoined, "This bag contains little mint-flavored disks of sugar about one-fourth-inch high and about large enough in diameter to fit into the groove of a window casing. I am a rather sound sleeper, and catch cold rather easily. Before I retire, I raise the window and close it down on about a dozen of these little disks. Then when the rain comes, it melts the sugar; the window drops; I don't wake up; and I don't catch cold."

The Lamme Medalist of 1941 is Forrest Eugene Ricketts. It should be—and in this instance it certainly is—a pleasure to be given an opportunity to describe the worthwhile achievements of any man, particularly when he is of one's own profession. Berton Braley has so well caught the spirit of this thought that I interject a line or two:

> "If with pleasure you are viewing
> Any work a man is doing
> If you like him, if you love him, tell him now;
> Don't withhold your approbation,
> Until the parson makes oration,
> As he lies with snowy lilies on his brow."

Friendship for over 30 years with the Lamme Medalist of 1941 makes the present assignment enjoyable indeed. Contact with a man over so large a span of his life—especially his working life—improves the perspective on his performance. Historians tell us it takes the lapse of a generation, sometimes of a century, properly to appraise the work of a man. This instance embraces a full generation of association. It brings to the account also somewhat of the credibility of an eye witness.

From the very beginning of and all through my contacts, Mr. Ricketts, in exposition of and argument for his ideas with other engineers, ever exhibited qualities basic to his character—consideration, tolerance, politeness, perspicacity, and perseverance.

Forrest Ricketts is a son of Maryland, a son of the soil of Montgomery County, vintage of 1878. He was not only born on the farm, reared on the farm, but remained on the farm until he was 24 years old. He attended Rockville public schools and academy, Columbian (now George Washington) University, and was graduated from Bliss Electrical School, where his laboratory reports were graded "excellent." In June 1942 the University of Maryland conferred upon Forrest Ricketts the honorary degree of doctor of engineering.

He first conceived the idea of entering upon an electrical career when, knee-deep in snow drifts and watching workmen clearing railroad tracks for the passage of trains, he was struck by the chance remark of his brother-

in-law that, if he ever had a son, he'd want him to study electricity.

Ricketts' first job in the field of practical electricity was with the Newport News and Old Point Railway and Electric Company as lineman and wireman. Later he was with the Philadelphia Mining Company of Chloride, Ariz., in the same capacity; with the Los Angeles Pacific Railway and Electric Company, as electrical repairman; and then with the Potomac Electric Power Company as working foreman of electrical construction. From the last-named company he was fired, with the statement that "Ricketts would never amount to anything." How prophetic of today!

In 1905, Mr. Ricketts joined the Consolidated Gas Electric Light and Power Company as an electrician. Since that time he has been chief operator, superintendent of electric stations, and director of intersystem power utilization bureau, and at present is vice-president of the company.

Forrest Ricketts is one of the early workers in the field of distribution of electric power, making contributions that have been in daily use for many years, and bid fair to be used for many more. While he did not attempt to patent all his novel ideas, it is clear that for the most part his 16 patents arose directly from problems solved in the course of his work. His clear recognition of the nature of the problem was largely responsible for his success.

He is often referred to as "the father of selective-relay protection," for he realized early the shortcomings as well as the basic advantages of the induction relay and, to remove the one obstacle to its extensive use on more complex systems, invented the "compensating coil," latterly known as the "torque compensator." In his own words, "Whenever I found something going wrong, or anything that needed improvement, I devoted all my time and energy to trying to work out something to improve those conditions."

GROWTH OF UTILITY INDUSTRY

If we had experienced through the years only the increases in the use of power for lighting and appliances, refrigeration and farming—even its use by the small industrial customer, the growth of the electrical industry would have been tremendously retarded. But as the industry grew, and the value of electricity as a servant began to be appreciated by more and more different kinds of heavy industry; when it was realized that electricity was about the most flexible, dependable handmaiden that could be found for the thousands of different kinds of applications that have since been made; when it was recognized that great progress had been made in the building of ever bigger and better, more efficient generating equipment, transformers, and apparatus for transmitting energy over long distances—then it also began to dawn upon engineers that the very extent of these developments was introducing certain problems that tended to work against the extension of electric service from generating station to remote industrial plant.

CONTINUITY OF SERVICE

These problems largely centered around the occurrence of interruptions. For certain industries, interruptions for even a few cycles are very serious, oftentimes spoiling a considerable part of the product; sometimes not only spoiling the product, but making it necessary to spend some days in getting ready to start production again.

This condition was not confined to plants served from a public utility—interruptions also occurred with companies which had their own generating plants, but in such cases at least, a plant was not subject to the interruptions that occurred as the result of the exposures of transmission and distribution lines of large extent.

For this reason, many concerns for years would not connect with utility systems or buy large blocks of power from them, and did not do so until they were satisfied with the progress in controlling the supply of energy so as to give dependable service of high continuity. That continuity of service was largely accomplished by perfecting the speed and selectivity of protective relaying and achieving quicker reclosure of circuit breakers. It was in precisely these directions that Ricketts made such great contributions. It is his kind of contribution, therefore, that has favorably influenced—in fact largely determined—the growth of big systems. Consequently, today many private industries have found the service of public utilities so satisfactory, so dependable, that they either have entirely discarded their own generating plants, or have retained them only as spare or partial sources of power supply. There are many concerns in the United States that have central-station loads of 30,000, 40,000, even 50,000 kw.

Since the award of the Lamme Medal to Forrest Ricketts was largely caused by his achievements in the field of power control, some of his outstanding inventions may be of interest. While his endeavors were by no means confined to this field, undoubtedly he is best known for his contributions toward the safe and sure control of power generation and distribution.

At the time he became associated with the Consolidated Gas Electric Light and Power Company of Baltimore, he found the protection of these systems from short circuits not keeping pace with the system growth. About the only protective relays available were of the straight, overcurrent type. While these could be given a suitable time delay for normal overcurrents, they operated almost instantly when subjected to severe short-circuit currents, because the operating force in a device of this kind is proportional to the square of the current. This was an excellent characteristic for small central stations having only a generator bus and several outgoing radial feeders; but when increased usage of central-station power brought about more complicated distribution systems, with main lines going out from the main stations to re-

mote distributing points whence branched out other circuits, this fast operation of overcurrent relays caused all the circuit breakers all the way back to the power house to be opened simultaneously for short circuits far out on a remote feeder. There was no selectivity; and there could be none, if all the relays operated instantly.

Mr. Ricketts solved this problem with his torque compensator, which was a kind of transformer placed in the current circuit to the relay and so designed that, when very high currents flowed in the circuit being protected, magnetic saturation would limit the amount of current to the relay.

An incident which is characteristic occurred during Ricketts' early developmental work on inverse time limit of relay action. He was comparing with a prominent consulting engineer their respective inverse time limit curves of relay performance, which on casual inspection looked alike. After an hour's discussion the consulting engineer made closer inspection of Ricketts' curve and exclaimed, "Oh, your curves are plotted current versus *cycles!*" His own curves were plotted current versus *seconds*. In other words, Ricketts was 60 to 1 ahead of the art!

Forrest Eugene Ricketts

In this manner overcurrent relays were given a definite time characteristic for heavy overloads, which meant that, working back from a remote feeder to the source, the successive relays could be given progressively longer time-settings, and thus allow time for the relay nearest the short circuit to open its circuit breaker before relays nearer the source would operate. This was the beginning of selective relay action, and the torque compensator is still in use today, with no basic change in principle after 30 years.

RELAYING OF PARALLEL CIRCUITS

Further loading of distribution systems brought about parallel lines between sources and distributing points, and for these a new problem arose. When a short circuit occurred near the load end of one of a set of parallel lines, the short-circuit current divided almost equally between the two lines. The two sets of relays at the source end—as well as the two sets at the load end—having the same current in them, could not distinguish which line was in trouble and so had to interrupt both, defeating the very purpose of the duplicate lines. Mr. Ricketts' solution of this dilemma was to devise relays that not only distinguished between the clear and the faulted line, but took out the time delay as well. In this connection he seems not only to have pioneered balanced current relays, but to have made most of the subsequent major improvements as well.

First, capitalizing on the fact that the currents in a set of parallel lines were equal if the short circuit was beyond the next station, but were unbalanced in either magnitude or phase or both if the short circuit was on one of the lines, he devised means for short-circuiting the torque regulator on the relay associated with the faulted line, thus allowing it to operate instantly and trip the proper circuit breaker.

Enlarging on this, he added ground current relays at both ends of parallel lines and reverse current relays at the distributing end, thus increasing the sensitivity as well as the selectivity of line relays. These devices, too, are still in wide use today in substantially their original design.

RAPID-RECLOSING CIRCUIT BREAKERS

Not satisfied with being able to disconnect short-circuited and grounded lines quickly and selectively, Mr. Ricketts also concerned himself with means for getting them right back in service as soon as the arc was interrupted. He had found that at least half the short circuits that occurred were of a temporary nature, such as power arcs following lightning discharges, and that in such cases an immediate reclosure of the line circuit breaker was successful in restoring service.

He therefore invented relays that not only would start immediately to reclose the line, several times, but also would limit the reclosures to a predetermined number. Thus service to a faulted feeder was usually restored immediately, instead of after the relatively long delay attendant upon manual reclosure, and in general, power customers were not even aware that an interruption had taken place. This idea not only has been applied to the majority of radial distribution feeders, but is rapidly being extended today to high-voltage tie lines as well.

In addition to his developments in the art of selective

relaying and circuit reclosing, Mr. Ricketts also turned his inventive genius to regulators, another factor of prime importance in the successful operation of a power system. He invented regulators sensitive to both voltage and current, whereby he could hold constant voltage either at the generating station or at some remote point in the feeder system.

It can be safely said that Forrest Ricketts himself is largely responsible for the present-day ability to protect and regulate large power systems so surely, so safely, so efficaciously, that the record of discontinuity of service is almost nil.

LAMME-MEDAL QUALIFICATIONS

The bequest in the will of Benjamin Garver Lamme provides for annual award to an Institute member of a gold medal to encourage interest in and give recognition to "meritorious achievements in the development of electrical apparatus or machinery."

One will go far to find a man contributing more than has the 1941 Medalist to the development of means to make possible the growth of power systems to present-day proportions. Mr. Ricketts' contributions to the art, through his many inventions, have had, and will continue to have, great value. He truly deserves the distinction and honor attached to the medal.

In a poem depicting "The Spirit of the American," Rudyard Kipling says:

> "Enslaved, illogical, elate,
> He greets the embarrassed gods;
> Nor fears to shake the iron hand of Fate,
> Or match with Destiny for beers."

The very antithesis of all these six specifications is the character of the American who is the Lamme Medalist of 1941.

As to "enslavement," Forrest Ricketts merits rather paraphrase of a passage of Holy Writ in the Gospel of St. John, "Thou shalt know the truth, and the truth shall make thee free."

Without inexorable "logic" in thinking, his continuing success throughout the years could not have been won; and stimulation to further achievement, rather than "elation" over ground gained, has been his guide.

The modesty of his approach to problems of man, method, or matériel has "embarrassed" no gods in his greeting; he shakes no "hand of Fate," in a spirit of predestination, but seeks solution of his problems with unwavering perseverance; nor does he gamble with "destiny" at all, but wins his way by following hard on the orderly arrangement of sure knowledge with unswerving assiduity.

In large measure, his success has come from practice of his own philosophy, which he epitomizes with "E's;" not the ease of "*dolce far niente*," but, in his own words, the "E's" of "Effort with Education and Experience."

In this award to Mr. Ricketts, in very truth, Honor follows Merit.

AIEE Lamme Medalists

1928	Allan B. Field
1929	Rudolph E. Hellmund
1930	William J. Foster
1931	Guiseppi Faccioli
1932	Edward Weston
1933	Lewis B. Stillwell
1934	Henry E. Warren
1935	Vannevar Bush
1936	Frank Conrad
1937	Robert E. Doherty
1938	Marion A. Savage
1939	Norman W. Storer
1940	Comfort A. Adams
1941	Forrest E. Ricketts

Luck and Accomplishment

FORREST E. RICKETTS, 1941 Lamme Medalist

I wish to express my appreciation of the honor that has been conferred on me by the Institute in awarding me the Lamme Medal for 1941. Naturally, I had been somewhat aware of my contributions to the industry, but I had not realized that they might be of special interest to the Institute. In the past, the awarding of the medal has always suggested achievement and progress to me. Now, I have a more complex reaction to the event, and I am not able to resolve my feelings clearly. At any rate, the award is particularly gratifying to me, because it has encouraged me to entertain the idea that I also may have contributed to the progress of the electrical industry. Realizing, as no one else can, how the turning points of my life depended upon chance events, I feel as thought I were being honored for being lucky.

I was born on a farm in Maryland, at a time when the electrical industry was beginning what was destined to be a most spectacular development. That was certainly luck for me. Of course, many others came into the world at about the same time, and even in Maryland, so those events do not, by themselves, fully account for my career.

While attending high school, I had already become somewhat interested in the electrical industry. However, after graduation, I lingered for several years on the farm. While I was not exactly dissatisfied there, I was evidently not altogether satisfied, as I decided to seek employment elsewhere.

Consequently I wandered to Newport News, Va.; Los Angeles, Calif.; Chloride, Ariz.; back to California; and then to Washington, D. C., living on the electrical industry in each instance. Although at the time I did not realize it, I was lucky in having these experiences, as they constituted a liberal education.

While in Washington, I was

assigned for a time to operate a rotary station where there was located a storage battery equipped with an end-cell switch for changing the voltage. The switch was controlled from the switchboard, and as it was free to stop at any position in its travel, it often came to rest short-circuiting a cell, in which case the switch usually would burn up. During spare time I rigged up an automatic control that allowed the switch to stop only in the correct position.

When this job was completed, and the device was working satisfactorily, I made myself comfortable at the desk. Unfortunately, I had failed to provide an automatic bell for the door, so that shortly thereafter, when the boss came in, he found me asleep. He was one of my fine bosses. However, on this occasion, he showed more interest in the ethics of operation than in automatic control. So far as I can now recall, I never did get the opportunity to explain my automatic control to him. Even so, I was lucky in not being fired, and in that he still entertained confidence in me.

In fact, I have always been lucky in having bosses who were rather extraordinary men, and somewhat liberal toward my inclinations to try new things. From my own experience, I would say that bosses generally are just about what you make them.

I do not mention this instance in my Washington experience on account of any direct connection it might have with the Lamme Award—the committee certainly did not know about it—but rather because I want to confess to a personal characteristic that seems to have been to some extent responsible for whatever new developments I may now be credited with.

This end-cell switch, and others like it, had repeatedly given trouble, of which many operators were aware without becoming interested. However, this same situation seemed to direct my interest to the mechanism of the switch until I could no longer tolerate its deficiency, and promptly set about to improve it. Since then I have literally enjoyed the many extra hours of work which it has been my privilege to spend on such problems.

After working in Washington for a while, I obtained employment with the Consolidated Gas Electric Light and Power Company in Baltimore, Md., by which company I am still employed. On arriving in Baltimore at my new job, I found what might be called an electrical menagerie: generating stations located here and there; direct current, 25, 60, and 133 cycles; single, two- and three-phase; several varieties of series-arc machines and machines not sychronized. There were even induction-type alternators. Can you imagine a better opportunity? All this lay before me, and at a time when the evolution that has brought the electrical industry to a position second to none, any way you take it, was just getting under way.

At about this time in Baltimore, the 120/240-volt d-c three-wire system was replacing the 250/500-volt three-wire system. This change left on our hands a number of rotary converters which, when operated at 250 volts, would carry only one half of their kilowatt load. It occurred to me that if we could connect the rotary winding in two parallel circuits, these machines would then carry full kilowatt load at half voltage. I mentioned this idea to my boss, and he suggested that I visit the factory and discuss the matter with the designer of the machines. That I did promptly, but was assured that my idea would not work. However, when I returned to Baltimore and reported the adverse opinions of the designer, I also stated that I was still confident that the rotaries could be made to operate satisfactorily at the lower voltage.

Permission was given to try the idea on one machine. The alteration was completed in less than a day, and the machine performed as anticipated. The trick was to advance the top wire in each commutating segment one step ahead, which gave two armature windings working in parallel instead of one in series, and to connect the field coils into two parallel circuits at half voltage. The transformer coils were also connected in parallel. However, there remained the problem of commutating currents of twice as many amperes as was necessary before the change. This problem was readily solved by using brushes of twice the thickness of those formerly used. This was feasible because the commutating point was now twice as wide as it had been before the change. Five rotaries were altered in this manner and they are all giving satisfactory service after more than 30 years. I have mentioned this problem because it again illustrates how relatively simple solutions to problems may often be found if we become deeply interested in the things we work with, and like the end-cell switch problem, its solution also serves to illustrate the characteristics that have been largely responsible for my receipt of the Lamme Medal.

When an honor of this kind is conferred on an individual, the effect is often to inspire others to high achievements in their own specialties. In fact, I believe that is one of the purposes of such awards. In line with that purpose, I venture to suggest certain generalizations concerning the development of new ideas, which have been corroborated by my own experience. First, you must understand your problem; then if you are genuinely interested in it, you are well on your way to a solution. But to reach the goal you must be persistent. Your understanding must be clear and visual, and your interest must be not only continual, but consuming.

In my case, I have had the good fortune to work under favorable circumstances, and to have had an abundance of problems relating to my responsibilities. What I have accomplished may be considered a natural result.

In conclusion, I confess that throughout my career I have been motivated solely by an interest in working on problems rather than by any thought of reward. I hope others will have the good fortune to find problems that will command their interest also, since there is still much to be done.

Democracy in Its Struggle Looks to the Engineer

D. D. EWING
FELLOW AIEE

A MAN once wrote a letter to the head of his government, offering his assistance in time of war. This man possessed a highly trained mind, a very creative imagination, and exceedingly skillful hands. He wrote, among other things:

"I have a method of constructing very light and portable bridges, to be used in the pursuit of or the retreat from the enemy.

"I have also most convenient and portable bombs, proper for throwing showers of small missiles and with the smoke thereof causing great terror to the enemy.

"I can also construct covered vehicles, secure and indestructible, which entering among the enemy will break the strongest bodies of men.

"I can make powders and vapors for the offense of the enemy.

"I have methods of making vessels . . . that shall resist the most powerful bombs."

A rather up-to-date list! Yet the letter was written nine years before Columbus discovered America and the writer was practically a contemporary of the fabled Arnold von Winkelried who with his own body breached a phalanx in the army of another Austrian dictator in order that the freedom-loving Swiss might live as men and not as slaves.

Toward the end of his recital of his capacities as a designer and constructor of military equipment, the applicant observed, as a sort of an aside: "In painting also I can do what may be done, as well as any other, be he who he may."

It would seem from the record that this skilled man's ducal overlord chose to make a greater use of his architectural and artistic skill than of his ability as a military engineer, and it could be reasoned that, as net consequence, today's balance sheet in the world's mythical hall of fame carries the name of Leonardo da Vinci as one of the greatest of the "Old Masters," while the house of Sforza is unknown and Milan is only an Italian city.

In da Vinci's time and for long thereafter, battles were won in the von Winkelried manner—by the impact of fighting man on fighting man—for despite the skill of men like da Vinci, military leaders were loath to abandon the old orthodox personal-combat style of fighting.

In the last analysis wars are still won by man power. To win, armies must still occupy cities and lands previously occupied by their enemies. The air over these cities and lands must be dominated by the air fleets of the victors. The ports and harbors, even the oceans, must be ruled by the naval forces of the winner. Our own war cannot be won otherwise than by the impact of our armed forces upon those of the enemy and by the displacement of the enemy from the land, sea, and air areas he now occupies. Let it be understood, here and now, therefore, that we have no thought of minimizing in any way the absolute ultimate necessity, in this war of ours, of the trained fighting man with a real fighting spirit; of vastness in the armies and in the navies of the sea and the air; and of the enormous sacrifices of freedom, blood, and treasure necessary for final victory.

There is an old saying that "Man cannot live by bread alone." There is a lot of truth in this saying, and it is just as true that today wars cannot be won by fighting men alone, no matter how good their fighting spirit, their discipline, their leadership, their individual resourcefulness and endurance, and their willingness to make the ultimate sacrifice for their cause. Bare hands just cannot be matched against tanks and airplanes, machine guns, and fire throwers.

The record of this war shows, if it shows anything at all to a layman, that to win, every type of implement of offense and defense must be instantly and always at hand and at hand in adequate quantity. "Too little and too late" has been the inseparable companion of calamity. To carry the fight to the enemy or to defend itself, an army must have "striking power." "Striking power" seems to be a matter of momentum—of mass and speed—and the destructiveness of the stroke a matter of mass and of the square of speed. The armies and navies of fighting men can furnish the mass factor in these dualities but in only a limited way can they furnish the speed element. To improve mobility and striking power Rameses and later overlords of the Near East used chariots. Hannibal and others used elephants, and the horse has been used since primitive times. These accessories to the fighting man's complement are well known. So are their limitations, and there is no point in mentioning them here, save that their use through the years has been an indication of the urgency of the need for increasing the speed factor in warfare.

When da Vinci "dipped into the future far as human eye could see" in the field of the military arts, he apparently saw vastly more and much further than his contemporaries. He saw the need of striking power and speed in forms more potent than animal power could give. He even had ideas about flying machines. And he

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must certainly have concluded that the von Winkelried fashion of warfare could be greatly improved upon.

And why now, half a millennium later, does "Democracy in its struggle look to the engineer?" Why does the United States, our great nation of free, self-governing men, fighting to save its fair lands from the depredations of marauding dictators, fighting for its ideals of freedom, of equality of opportunity, and of free enterprise, look to those who are trained in "the art of organizing and directing men" and who, by using the facts and laws of science, can control the physical "forces and materials of nature" in an economic manner "for the benefit of the human race?" Why does the British commonwealth with its heritage of half a thousand years of practice in the art of self-government and in the art of defending its ideals and its lands look to the disciples of Watt and Rankine, and the famous Thomsons, rather than to the disciples of Marlborough and the Iron Duke, or to the shade of Coeur de Lion? Why do other peoples less fortunate in their national heritages, but nevertheless as freedom-loving and as individualistic, look to the engineer, the man trained in the creative sciences and arts? Why? In the first place, because for three quarters of a century the genius and skill of engineers and other scientific workers have brought to them the useful things and the luxuries of life—opportunities for employment, high wages, transportation, communication, comfortable homes, and good food, to name a few—which have made America a Mecca for the rest of the world. The peoples of the democracies look to the engineer because they have come to have confidence in him as a worker of modern miracles.

The engineering genius that has given the United States the world's highest living standards in peacetime can put into war materials the speed factor needed to overcome the inefficiency that is part of the price of democracy, according to this engineering educator, who believes our production experts will convert "too little and too late" into "enough and on time."

Secondly, because machines play such a great part in modern warfare, and machines are the brain children of engineers. Thousands of engineers are required in the uniformed services simply to operate and maintain the modern "engines of war"—battleships, airplanes, tanks, docks, airdromes, trucks, guns, detector systems, communication systems, roads, bridges, and army camps. The modern soldier often must be a mechanical technician as well as a fighting man, and the training of technicians is in part an engineering job.

Thirdly, because the present war presents three great civilian problems connected with the defense industries: organization and direction of civilians in the defense industries, the need for superiority in production machinery, the necessity for superior quality in war matériel.

It has been said over and over again that this is a war of materials and equipment. But it is much more than that. When, if ever, in the history of the world were such great numbers of men under arms? Whenever were there such vast navies of the sea and of the air? Whenever were so many men needed in the manufacturing and transporting of the materials of war to the armed hosts? Whenever were so many men needed for work in Earth's storehouse of raw materials? In what other war were so many men needed to service and maintain the implements of the warriors? The wild-riding hard-fighting hordes of Genghis Khan and the armies of whip-driven slaves of the pyramid-building Pharaohs were not, in numbers, comparable to the armies of today, and their services of supply and maintenance were practically nonexistent.

Of the three problems, one involves the organization and direction of the great army of civilian workers who man the cargo fleets of sea and air, the factories, and the sources of raw-material supply. Of course, others beside engineers organize and direct men. In the armed forces that is one of the prime functions of the admirals and the generals. But where the work involves construction, production, transportation, and communication, it is peculiarly in the field of the engineer. It is true that this work has to be done under pressure and that it is of an emergency character. But engineers have long been accustomed to working under pressure and dealing with emergencies. The forces and materials of nature, with which the engineer works, often seem, at least, to be engaged in wars of their own.

But in order to construct, produce, transport, and communicate, the worker must have the necessary equipment. This constitutes the second problem. We have all heard many times over that the United States has more railroads, communication lines, automobiles, hard roads, radios, refrigerators, bath tubs, and so on, than any other country in the world. It takes production machinery and skill to produce these things. Our production men long ago taught themselves the art of mass production and then out of the goodness of their hearts generously gave of their knowledge and craft to other peoples of the world for their betterment. Some of these other peoples now are our enemies, but we believe that our people who were the originators and instructors are still a long step ahead of their ungrateful pupils.

The story of production, from iron mine to army tanks, for example, is a long one—explosives, power shovels, mine cars, docks, ore-loading equipment, lake steamers, canals, locks, railroads, ore-handling equipment, blast furnaces, red-hot ingots, rolling mills, forge shops, machine shops, jigs, fixtures, automatic tools, giant presses, all feeding into great mechanized assembly lines for tanks—a saga of mechanisms, and a tribute to the

workers, technicians, and engineers and to technology.

The two problems which we are now discussing might well be merged into one problem—the pressing problem of "too little and too late." This problem is a fighting challenge to the production expert. It irritates him as a red rag is supposed to irritate a bull. His watchword always is "enough and on time." Give our production engineers a chance, cut the red tape, pork-barrel strings, and the other fetters that hamper production, and "too little and too late" will become a forgotten phrase. Here in free America the peacetime ramifications of this problem have been solved in a way not even approached in other countries. Fortunately, no new principles or inventions have had to be developed to meet the wartime aspects of the problem, but unfortunately many new machines for tooling our war industry plants have had to be built from the ground up.

The third great problem is that of putting the "invisible ingredient"—the speed factor—into our wartime maétriel; putting that quality into our guns, our ammunition, our ships of war, our airplanes, our tanks, and all the other equipment, so that in time of battle and in the preparation for battle, our armed forces may have the necessary striking power, the military momentum—the mass factor of their numbers combined with the speed factor of their equipment—that will enable them to strike decisively and with destructive energy in every blow.

For surely it is as true in war as it is in peace that "To him that hath shall be given, to him that hath not there shall be taken away even that which he hath."

Democracies, say the dictators, are slow and fumbling, are lacking in the ability to make decisions, are spineless, more interested in money than in national honor; are unwilling and unable to fight. In some of these charges there may be some measure of truth. In times of peace in the United States, the duly elected chief magistrate cannot arise some morning after an attack of insomnia and order our armed forces to invade the lands of a neighbor. Free men feel that war is some thing in which they are or will be vitally concerned and so do not permit the making of major decisions in such an irresponsible manner.

The extra costs to us as a nation and as individuals of having to make up quickly for our neglect of defense are part of the price we must pay in order that in normal times we may order our lives as we will.

There is also a tendency in times of peace to forget that every country in every age has needed armed forces for protection against external aggression. We have always recognized that such forces in small number are necessary for internal policing, but we have depended on natural barriers and our fleet for protection against aggression, perhaps unduly. Britain has done the same thing and done it quite successfully for the past 800 years. New inventions and new developments in the arts of war have changed things, however. The old defenses are no longer real protective barriers. Until suitable replacements for these barriers can be found, war is likely to find the free peoples more or less unprepared to defend their freedom. Despite our experiences of the last war the United States was almost wholly unprepared for war two years ago. We had been having our depression troubles and had given little real attention to the rumblings in Europe, which seems to be in these later centuries the playground of Mars.

We are having to make up quickly for the negligence of bygone years. Hurry-up work is usually not done economically and efficiently. The extra costs and labor to us as a nation and as individuals are part of the cost of freedom, part of the price we must pay in order that in normal times we may order our lives as we will, without let or hindrance from a prying, arrogant, and dictatorial governmental Gestapo.

How can this inefficiency in the maintenance of the national-defense mechanisms be met? Materials, equipments, the direction of men, and the application of the laws of science in production are engineering problems. Our inefficiency in defense maintenance can be and is now being remedied by the application of scientific methods to the production of war necessities.

Are we willing to spend money to defend our honor, our homes, our lands, and our ideals? The records show that we are. We were not stingy in money matters during the last war. We were probably too generous in every way then, with our vanquished foes. We are not being stingy in this war. What nation ever spent at the rate of $50 billion a year, measured either in dollars or in the amount of the world's consumable goods that the dollars will buy? Can freemen fight? History says yes. The free warrior, man for man, has always been the superior of whip-driven serf or the fighter for wage. A thousand battlefields from Marathon to Bataan attest this. Only when free men become so familiar with freedom that they forget it is a priceless heritage, to be maintained only by strenuous effort, and turn their affairs over to bureaucracies or to self-anointed and self-appointed leaders, do they become supine, spineless, and unwilling to fight. Have we in the United States come to this stage? Von Ludendorf did not think so 20 years ago when he wrote in a spirit of bitter admiration that the United States understands how to make war. He knew from bitter experience that our fighting forces knew how to combine mass and speed to secure irresistible momentum and destructive striking power.

What assurances do the American people have that by the application of basic engineering principles in war-material and equipment production we can overcome the inefficiency and losses caused by our lack of preparation and the slowness of governmental decision?

There was a great deal of comment in the months be-

fore and immediately after Pearl Harbor criticizing rather caustically the apparent slowness of American industry in shifting from the production of peacetime goods to wartime necessities. This criticism came from many groups of our citizens; even some engineers waxed emphatic on the theme. To most people not connected intimately with production, a shop is a shop, tools are tools, and workmen are workmen. They see no reason why a shop that is equipped to build, let us say sewing machines, today, cannot start tomorrow morning in full production on machine guns. Few realize that such a procedure would entail the complete retooling overnight of a shop, the tooling of which for the peacetime product may have been a developmental process extending over a long period of time. As an example, for a certain well-known type of gun, retooling might involve a matter of 10,000 gauges, 6,000 jigs and fixtures, and other tool items in proportion. Certainly this is not a holiday week job. Further, such a change involves new and different inventories of stocks and a complete retraining of the production workers from messenger boy to works manager.

Our negligence and inefficiency in the maintenance of national-defense mechanisms is now being remedied by the application of scientific methods to the production of war necessities.

Production men will recall that it took nearly two years for one of the large automotive manufacturers to change models completely when the change had to be made without the usual two or three years of advance preparation. To me the changeover here in America has been little short of miraculous. I take off my hat to the men who have done the job. Everywhere we now hear of new plants, old plants, rebuilt plants, one and all setting new production records in war materials and equipment. What can be said now is that no nation ever worked such wonders so quickly. Furthermore the products have built in that extra quality so necessary for the Army and Navy in field of war. Here in America the assurances of our success in this matter are all around us. Our homes, our food, our clothing; our electric lights, refrigerators, sewing machines, washing machines, and vacuum cleaners; our motor cars, radios, telephones, telegraphs, railroads, trucks, tractors, farm machinery; our factories, and so on, ad infinitum, attest to the ability of the nation to produce needful and desirable things. Willow Run, the Chrysler tank arsenal, and unnumbered and unnamed other great plants exemplify the speed with which open country can be changed into high-capacity war-material production plants.

Our greatest assurance is that during the last three quarters of a century we in the United States with shorter working hours, have achieved a higher standard of living, and a greater abundance of the things that make life worth living, than has any other country in the world. The totalitarian powers with their longer hours, their stricter discipline and restriction of the individual, have achieved no such results. Even the results they have achieved in peace and in war have been largely the work of the copyist and not of the originator. Count the great inventions of the last 150 years and note their countries of origin. The cotton gin, steamboat, telegraph, telephone, electric light, phonograph, typewriter, cash register, sleeping car, safety razor, linotype, radio, reaper, automobile, vulcanized rubber, cellophane, power farm machinery, aluminum-reduction methods—all are evidence of American genius. Someone has computed that no less than 75 per cent of the great modern inventions are of American origin. No mere chance occurrence this, but the result of free men working with untrammeled minds in and for free enterprise. Driven men look downward and sidewise and not upward and outward. Dictators are surrounded by "yes" men and not by men with clear vision and creative imaginations. The Whitneys, Fultons, Whites, McCormicks, Morses, Bells, Goodyears, Pullmans, Achesons, Edisons, Baekelands—only to mention a few—and others of the inventors clan do not thrive under a despot, however benign. Masters of ideas, of things, and of the forces of nature, they need the clear, exhilarating air of freedom in order that they may thrive to advantage. Our own great engineer, Steinmetz, seems to me to be an excellent illustration of this idea.

Our enemies seek a "place in the sun," "a more abundant life," by the methods of Cain and Esau, by taking the wealth of the frugal, the industrious, and the creative folk of their own lands for their camp and court followers, and when this source is exhausted they seek to prey on the wealth of other lands.

We in America have not acquired our wealth of goods and our high standard of living in this way. As a people we have worked, and worked long hours, to convert a wilderness inhabited by a few roving tribes of savages into a great and wealthy commonwealth. Our system of education, our patent system, the fight to maintain ourselves in a new land, freedom from restrictions, and good government have worked, in the last 150-odd years since Washington was inaugurated as President, to develop the creative genius, the high idealism, high level of living conditions, the spirit of fair play, and the straightforward ways of thinking and acting that have made the United States both admired and envied by the rest of the world. Can we give to our army and navy the speed component of their striking power by giving them in time and in plenty superior weapons and equipment? Engineers who plan and design, and their coworkers on the assembly line, in the tool room, on the test floor, and in the fabricating shops know that we can and that we will. The democracies of earth shall not look to the engineer in vain.

A Backward Look for a Forward Plan

FRANK C. HOCKEMA

THE TRAGIC DISORDER of the world of today will have an inescapable influence upon the whole future of our American social, economic, and educational systems. Bacon, in *Novum Organum*, said, "If a man will begin with certainties he will end in doubts, but if he will be content to begin with doubts he will end with certainties." A backward look, with doubts, over the changes that have taken place in higher education during the past few years, especially the last two years, and the proper appraisal of them will give us an outlook with some degree of certainty on the changes which we may expect in the near future and enable us to make plans accordingly. The national defense program has imposed immediate changes upon institutions of higher education—changes which in all probability will have an enduring effect. Other lasting changes are certain to result from the economic and social problems which we already have encountered and those which we are bound to face after this world catastrophe.

The present demand for trained individuals with good health and surplus energy has placed a new and greater emphasis on all phases of education. In this changed world, we are recognizing the need for reformulating the objectives of our educational system, for considering such departures as, for example, the provision of programs based on the aptitudes of the individual student and terminating when the limits of those aptitudes are reached instead of at four-year intervals. The opinions of some nationally known educators and employers of college graduates are cited in this article, which may be regarded as a straw in the wind.

The war has compelled us to put everything under the microscope. We hear that we need more and more trained men and women; that we are complacent; that we are soft; and that we must revamp our educational system. Abounding plenty during the past several years has not mothered many notable virtues in us. Threatened scarcity and rationing of the things to which we have become accustomed may bring us back to earth. During the past few months, education has become a stern and serious process. The critical situation of the world today—complacent confusion, frenzied fear, grotesque greed, heated hatred, silly superstitions, and sordid selfishness—demands men and women whose horizons extend far into the future, like the early settlers of the United States. It calls for men and women who can see beyond the things of a temporary and passing nature—beyond the confusion and the fear and the hatred and the bitterness and the greed and the selfishness generated by war—who are willing and ready to combine their powers and efforts to chart the road to progressive civilization. That road must necessarily be paved with tolerance, understanding, justice, and fairness, with due consideration given to minority groups. The debris resulting from civilization in reverse must be cleared away and civilization rebuilt on a sound basis. The brunt of this assignment will be allocated to the American school system, both public and private institutions. Much attention will have to be given to the elementary and secondary schools where the foundations are laid for the most significant part of American citizenship.

Doctor A. G. Grace, in his bulletins "Learning to Make a Living" and "Living and Making a Living," lists the following general objectives of public education: self-motivation, vocational preparation, moral integrity, civic responsibility, intellectual competency, cultural appreciation, and physical well-being. In an age of mass production of machines, there is a tendency among educators to apply similar methods of mass production to the American school system. This, of course, is a natural tendency, and to some extent it is inevitable. While standardization is a step forward in the industrial field, it does not necessarily mean progress in the field of education. It is not always sound procedure to apply to human beings

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methods which worked in the material realm. Each personality is distinctive and must be dealt with as such. Each community should develop the particular kind of education which best suits the needs of its people and the opportunities it offers.

In the past the shortage of opportunities to learn trades made boys and girls the victims of an educational system that had no connection with the art of earning a living, and that headed them toward the human scrap heap. Since the beginning of World War II the educational institutions, trade schools, apprentice schools, and industries have joined hands and are endeavoring to develop the powers of large numbers of men and women by putting a book in one hand of each and a tool in the other. The sole object of this joint program is to teach self-reliant citizens to work in various fields necessary to the national defense program. This training is not only preparation for practical living but is also a stimulus to independence of character. Because of individual differences it should not matter whether the service be painting masterpieces or lumberjacking, writing novels or driving a grocery truck, leading an orchestra or cultivating a tract of land, commanding the applause of audiences or teaching in a remote district—*if the particular job exercises all of the individual's best powers, that person will be doing all that anyone can hope to see him do.*

The national-defense and war programs have provided thousands of new jobs. The scarcity of qualified workers to fill these new jobs is testing our educational system and finding it wanting in many respects. Formerly we spoke of standardized four-year prescribed courses, and now we offer special short courses to thousands to train them on a job or for a better one. The longer the present plan is in effect, the greater its influence will be on our future educational program. Many employers maintain that entirely too much time has been wasted in teaching nonessentials and not enough devoted to fundamental courses and to teaching students how to think.

In order to train the youth of tomorrow most effectively for its work in a changed world, a careful study must be made of the factors involved in such training. To this end a careful and sympathetic, yet practical, approach to the subject has been made through leading educators, to whom we must look for the supply of material, and through business and industrial organizations, to which we must look for the use of this material. The ideas of nationally known educators, educational officials, college and university presidents, members of research institutions, and business and industrial executives are incorporated in this article. These will serve us in the training of youth for tomorrow.

To attain the fullest measure of satisfaction from living and working, every American citizen of tomorrow should have an opportunity to receive just as much education as will be of real benefit to him. This certainly does not mean that all should have an equal amount of schooling. Some individuals who have been admitted to high school reach the limit of their mental capacity before the end of the first year; their intellects will not continue to develop if they remain in school longer. Others are so constituted that they will continue to grow mentally through several years of advanced study; for them our graduate schools are organized. However, the vast majority of our population—many of whom have neither the mental capacity nor the academic preparatory training for college work—has come to regard college and advanced degrees as necessary stamps for social approval and business, industrial, or professional success. This is most unfortunate. During each of the four years of high school and the four years of college, a certain number of students reach their limit of academic progress, because of limited intelligence or because they are in fields of training which are not in line with their interests and aptitudes. There are others who, having finished the basic work given in the secondary or preparatory school, can profit greatly from certain types of vocational and academic courses given in college but who will not benefit from subjecting themselves to all the courses required for a degree. These men and women might well be given an opportunity to take certain work in college, outlined in a definite curriculum but not leading to a degree. No doubt most of them should be advised to supplement their college course with work in an apprenticeship, a trade, or a vocational school. Tact, as well as ability to estimate individual differences, will be needed to overcome the objections of the students and the parents who believe that a different type of education means an inferior type and consequent social inferiority. Perhaps the college should place on such students a stamp of approval in the form of a certificate of achievement after the completion of courses shorter in years and different in kind from those required for the diploma.

As one outstanding educator puts it, "The great weakness in youth education today lies in the fact that it is still entirely too academic. A million and a quarter young people will be graduating from high school this year. Two thirds of them will be prepared for college. A third of them will go to college and many of those will not stay in college very long. That is not a system of education in keeping with the mechanical age."

It is timely to provide American youth with adequate educational facilities and competent teachers. We have an annual crime bill estimated at 15 billions of dollars; a large portion of this enormous sum could be saved in educating the potential criminals to become legitimate wage earners. An improved educational system that would teach young men and women to cope with poverty, monotony, and the feeling of being "not good enough"—the chief causes of desperate deeds done in defiance of the social order—would do much to reduce the overwhelming crime bill. A reasonable portion of the saving might well be used to pay higher salaries to competent teachers and to provide for the necessary additional educational facilities and the necessary additional

teachers. Upon the elementary school teachers must be placed the enormous first responsibility of teaching and developing devotion and loyalty to the democratic form of government.

The present defense situation has called our attention also to the physical welfare of children and youth. Health and physical fitness are so vital to social progress, as well as to the individual's happiness and success, that every movement toward their conservation should appeal to the good citizen.

Another effect of the present war is the increased attention which is being given to vocational training and preparation by the entire school system. This attention will undoubtedly increase in the future and will give more prestige to manual work. During the past decade there has grown up a curious antipathy to manual work. Now everything depends upon whether the individual worker understands his work and what it means, what part it plays in the human economy and national defense, and whether he is ready and willing to do his level best to make it productive. The United States has lately come to realize that the mechanic is one of the most important men in our first line of defense. We are now paying tribute to men who know how to work with their hands as well as with their heads. Men who have never worked with their hands have missed something of great importance. There is a quality of sturdy, confident, intellectual approach discernible in those who have been trained to work with their hands and have acquired manual dexterity. Because of the war, people who work in factories, especially the skilled workers, are being paid very high wages. In the future there will be less distinction between the white- and the blue-collar workers. This will have its effect on college and university postwar programs.

The increased attention given to vocational training by elementary and secondary schools will probably divert a much larger number of pupils into workshops, trade schools, and apprenticeships, while the academic group will pursue a college course ranging from one to seven years in duration on the basis that needs of the student shall determine his curriculum.

Men and women with different backgrounds, who need and want an education in order to become the highest type of citizens of which they are capable, represent a great diversity of ambitions, attitudes, and abilities; many degrees of preparation; and a great spread of intellectual, social, vocational, and professional ideals. Since it is a democracy's duty to educate the educable, provided they want to become educated, the question arises, who should attend institutions of higher learning, and for what and to what extent should they be trained?

Another question is, what is to become of the institutions of higher learning? The world crisis, bringing with it an unpredictable economic condition world-wide in scope, has already affected the institutions of higher learning—the endowed institutions because of diminishing gifts, contraction of the securities markets, and the decline of interest rates; and the state-supported institutions because of a diversion of taxes to defense. This will probably mean a curtailment of the institutional activities, and for a large number of the smaller institutions economic collapse, either now or in the near future.

AIMS AND PURPOSES OF HIGHER EDUCATION

Educators and employers vary widely in their definitions of the aims of higher education. The question is, how should students be trained in colleges and universities to be equipped in the best possible manner to meet the present and future needs of the professions? Most of the educators and employers are agreed that technical students should have a thorough grounding in fundamental principles, should know how and where to find the information which they do not already have, and should know how to think. Most of them agree that students should be given thorough basic work in such courses as English, mathematics, physics, and chemistry. The question immediately arises, should not the student with creative ability, who is headed for research work as a career, have an opportunity to take much more advanced work in mathematics and other scientific and technical courses than the student, for example, who is headed for a career in the field of technical selling?

The following ideas, gleaned from educators and employers, represent a summary of opinion on the aims of technical education:

1. A more thorough training in fundamental principles which, in many instances, will mean eliminating specialized, irrelevant, and flubdub courses from the curricula. These fundamentals, with simplified presentation, should be brought into the curriculum *earlier*, on the theory that the intelligence of the student does not grow during his college career, although his experience and judgment should do so.

2. A concentrated attempt to teach the student how to think, giving each one the greatest possible opportunity to develop his own capacity, which means subjecting him to every stimulus that can be provided which will awaken his interest and develop his imagination, initiative, and skill.

3. Development in each student of an appreciation of the cultural side of life, "human" engineering, and an open-minded, cooperative attitude.

4. An effort to make each student a self-sustaining unit within the social order. To instill successfully in the student an abiding sense of responsibility to the community, state, and nation, it will be necessary also to prepare him vocationally or professionally to discharge that responsibility; otherwise, the knowledge of the responsibility is futile.

COLLEGE STUDENTS

The increase in enrollments in colleges and universities during the past two decades has created many problems in the minds of educators, students, employers, legislators, and taxpayers. However, in the years just ahead the colleges and universities are likely to be faced with a marked decrease in enrollments, especially of those

students who are able to complete a prescribed four-year course and those who are qualified for graduate studies. Several institutions are already engaged in sponsoring a large number of short-term defense training courses, many of which would also be valuable for students who are not qualified to pursue the prescribed four-year, five-year, or six-year course leading to a degree. In almost all cases, students who complete the short-term defense training courses are awarded a certificate of achievement. These same institutions have failed to award certificates of achievement for work completed by students who terminated their university careers after one or more quarters or semesters of university work, a part or all of which may have been satisfactory.

Less than 40 per cent of the students admitted to technical colleges complete the prescribed courses leading to a degree. The majority of the other 60 per cent fail as a result of poor teaching, unsuitable curriculum organization, and improper methods of admission. Approximately 50 per cent of the students admitted do not finish university work leading to a degree because of so-called "scholastic failure" and approximately another 10 per cent drop out from such causes as ill health, financial difficulties, or other personal reasons.

Colleges should maintain high and exacting standards of achievement for those to whom it gives the stamp of approval for work in the fields of public service, research, manufacturing, and the like, regardless of whether the approval be indicated by a certificate of achievement or a diploma. A few institutions are able, by means of careful selection, guidance, and counseling, to graduate within the prescribed time approximately 80 per cent of the number of students admitted. Some of the endowed institutions of higher learning at the present time have enough applicants for admission to make it possible, by means of rigid entrance examinations and personal interviews, to admit only the best. On the other hand, the state-supported institutions, with but a few exceptions, admit all the students from the state who meet their rather lax entrance requirements.

College students should be carefully selected. Because applications and letters of recommendation from friends frequently oversell or undersell a student as a result of personal reactions, it would be well if each student could be given a personal interview. Scholarship, personal appearance, personality, proper mental attitude, character, initiative, health, and endurance should be given due consideration. The directors of admissions in many colleges and universities state that in spite of improved standards for admission to the university, the faculties in practically all cases continue to fail approximately the same number of students on a percentage basis, and the percentage of "A" grades, "B" grades, and so on, fall within the very narrow limits of the old traditional grade curve. This brings to our attention the fact that the age-old problem of grading students will always be before us. Volumes have been written on grading systems. Many educators feel that the grading of students by outside committees would give the instructor an incentive to try to teach his course so that the maximum number of students would be able to make a satisfactory showing, whereas in the present system where each instructor does his own grading, many instructors boast that they are good teachers because they fail so many students.

A dean of a graduate school says:

". . . We believe that the general attitude of educational people is, as a whole, entirely wrong as regards their students . . . . In so many institutions the whole attitude seems to be that of a total entering class a certain percentage, say 15 to 25 per cent, must be failed during the first year. To me this is simply ridiculous. These young people coming to us are the raw material out of which we, the teachers and administrators of educational institutions, must fashion our finished product. What would happen if the ordinary business man started in at the beginning of the year with the definite intention or policy of spoiling 15 to 25 per cent of the raw material which was to be processed in his plant? The majority of us would say that that individual was a plain fool. In our own case, we have endeavored to salvage every single student that enters this school, and I have felt that we have only done our duty if we could take men who were about to fall by the wayside, put new pep and enthusiasm into them, and carry them through their courses of study to a successful conclusion. Some such men have turned out to be among our best alumni, and, once having found themselves, are now going forward by leaps and bounds. It would have been tragedy to permit these boys to fall by the wayside."

An employer of a large number of college graduates says:

"Another failure of engineering schools, from the employer's standpoint, is that he finds difficulty in selecting a man on the basis of his standing in college. The student with apparently the very best standing may be merely a 'memory machine' and, therefore, of little value to the employer. The turnover in the employment of young engineers is altogether too great. The employer can obtain some idea of the personality of the student from an interview but he must rely wholly upon the college standing of the young graduate for an appraisal of his mental ability. Since today a student's standing, as evidenced by his 'marks,' merely indicates his application which is valuable and his memory ability in memorizing facts and formulas, it does not disclose, at least independently, his ability in perception and reasoning which is one of the chief characteristics in which the employer is interested. To apprise the student better of his educational progress and to aid the employer in his judgment in the selection of engineering graduates, an entirely different system of marking must be employed."

Many of the students complain that, instead of being allowed to obtain the maximum benefit from the course through individual thinking, they are forced to mimic the professor in order to secure a good grade. This practice on the part of certain instructors results in the evil of encouraging students to take those courses, because they know they can make good grades by merely repeating to the instructor the material he has given them. Many educators condemn our present grading system, because the keen competition tends to produce dishonesty, especially among the slower students.

The following statements from prominent educators show some methods of teaching students to think and to

learn the fundamental principles of the courses without waste of effort:

"It is my conviction that it is necessary for the student to understand what is to be accomplished and why and to be completely sympathetic with the aims and objectives if the results are to be successful. Little can be accomplished when working at cross-purposes. The time spent in orienting the student's point of view will pay large dividends. It soon develops that, in addition to personal qualifications, the things that contribute most to the success of an engineer are analytical ability and facility in the use of basic principles. These cannot be developed by memorizing textbook assignments. No text is used. They [the students] study the subject instead of what someone says about it. They are treated as young engineers rather than immature students and they respond accordingly. My function is to provide questions, problems, and general guidances, theirs to evolve the answers and solutions out of their own personal experience. Progress is built on their experience, not mine. Their first problem is to formulate, out of their knowledge of physics, five or six fundamental principles which will enable them to solve most of their problems . . . . They can supply most of the facts but need help with the wording to meet the foregoing requirement. The next step is to give them a problem with which they are unfamiliar and let them find the answer by applying the appropriate principle or principles. Of course, it is difficult for them the first month for they are on the delivery end—a new experience. Help is necessary at this stage but it is usually in the form of more questions rather than supplying the answer. Soon they find that they can solve new problems without help and are greatly stimulated by the discovery. They are thrilled by the power of personal accomplishment and this results in a further development of intellectual curiosity.

"In the early stages it is essential to provide problems of the proper difficulty, for this is a period of building up confidence. Later they can take harder blows. They like the idea of being treated as engineers."

"There is no pedagogical value in requiring the students to repeat over and over again calculations that all follow the same general pattern. Each student is, however, required to make two or three computations of each type.

"The administration of the laboratory work is entirely under the supervision of a 'foreman,' chosen in rotation from the members of the squad. There are instructors in the laboratory, but their duty is merely to be sure that no accident occurs that might injure either a person or a piece of equipment. The entire responsibility for the laboratory procedure rests with the foreman. Some time before each laboratory period the foreman consults with the instructor and arranges with him as to the procedure to be followed. The foreman then arranges the work in detail, prepares the data sheets, and instructs each man in the squad as to his individual duties. Before the laboratory period begins the foreman may consult with the instructor; when the period starts he assumes full and complete responsibility. His responsibility terminates only when the experiment is satisfactorily completed and the data book has been approved by the instructor in charge.

"Our success with the system of administration has been remarkably satisfactory. It develops in the student the ability to organize and supervise the work of others; this kind of training is regrettably lacking in most university courses. Because the men know that they are acting on their own responsibility, they do really careful and serious work; we have fewer errors than we had several years ago when the laboratory work was under the supervision of an instructor. The suggestions made by the 'foremen' in planning the work have often led to very marked improvement in the procedure."

Many of the educators feel that the student should be put on a program of study gauged to his previous training, learning rate, capacity, and interest, so that he has an opportunity to make the progress of which he is capable. In a three-credit-hour course, the slow student, for example, would receive five hours of instruction per week, whereas the fast student would receive three. Most of the low-ranking students and many of the average ones would terminate their study programs in one, two, three, or four quarters or semesters of college work. Many of these students should be transferred as soon as possible to vocational or trade schools in order that they might become better equipped to meet the needs of their prospective employers.

A few colleges and universities divide the undergraduate work into what are known as the junior college and the senior college. The junior college, which usually embraces the first two years of the undergraduate work, not only prepares for the senior college those students who are qualified to complete its work, but also provides terminal courses for those not equipped or prepared to master the study program leading to a degree. All students, when they first enroll, might well be put under the guidance of counselors who would help them determine the vocations or professions for which they are best adapted; plan a program of study to fit them for these vocations or professions; and guide them in their adjustments to educational and personal problems.

CURRICULA FOR THE TRAINING OF COLLEGE STUDENTS

Employers of engineering graduates naturally are looking for competent individuals who can fit into a particular job in the shortest possible time and with a minimum amount of training on the job. If engineering colleges are to train leading citizens who will put more into this world than they take out of it and who possess such qualities as character, enjoyment of work, initiative, mental alertness, common sense, loyalty, good judgment, ability to get along with people, good appearance and mannerisms, health and endurance, willingness to assume social and community responsibilities, curricula must be provided which will give adequate training to such individuals.

Instead of fitting the student to the curriculum, as is so often the case, the college should fit the curriculum to the student. A student, with proper advisers, can map out a program of study, activities, and experiences which best match his aptitudes and abilities. For some students this training may be broad and general, and for others it may be specifically vocational. If an engineering college has only one curriculum, only students with the proper aptitudes and abilities to master that curriculum should be admitted. There seem to be at least a few important items upon which all educators and employers agree. These are that every college man should be: (1) a master of the English language in both the written and spoken form, (2) thoroughly trained in fundamentals, (3) a thinker, (4) personable, and (5) a good citizen.

The following comment is from a prominent employer:

"Engineers have an obligation not only to apply the technical knowledge which they have been taught, but to carry the burden of inventing, developing, manufacturing, and selling the new and tremendously improved facilities for living which future generations will enjoy. Somewhere in an educational program should appear a stimulus to this faculty. A proper co-ordination of imaginative and conservative thinking should produce the things we need, in their proper order and at the proper time for our economic assimilation."

Another employer has this to say:

"Surveys show that a very large per cent of the engineering graduates do not follow the type of engineering in which they specialized at school. A very large portion of their time and effort spent in this specialized training is lost except as it teaches them to stabilize their thinking, and to apply the basic theories and fundamental principles to their problems. An attempt on the part of some schools to crowd in a great deal of material has so overcrowded their curricula that the students receive a superficial rather than a thorough training in the subjects taught. Our own experience and the experience of others in the industrial field convinces me that once the men acquire healthful work habits, a clear reasoning power, and the habit of thoroughness, knowledge along a specialized line which they may be following is readily acquired.

"The subject of human relations is becoming more and more important in the engineering field and we find the majority of the technical graduates are wholly unprepared to cope with the problem. The engineering student finds that so much time and emphasis has been placed on purely technical studies that he has no opportunity to study such subjects as human relations, supervisory methods, administrative procedures, etc. He finds himself ill-equipped to meet such problems when they arise. Actually, when engaged in his work, the engineer finds himself confronted with as many human-relations problems as do most people in other lines of endeavor. A degree of supervisory ability may be an inherent characteristic of some men, and some may acquire it 'on the job,' but certainly education of this type would prove of inestimable value to the engineer as he progresses in his chosen profession."

Several of the employers of college graduates suggest that colleges and universities give more attention to providing practical experience for students. The following plans were suggested:

1. Co-operative planning in the form of alternate months of work and classroom study.

2. Work experience as a prerequisite for admission to the university, this experience to be obtained either immediately after the completion of high-school study or after the satisfactory completion of the first two years of college work.

3. Interneship in industry. This would be supplementary to the university training in that the student would be required to spend a definite length of time—one, two, or three years—as an interne in his profession.

The majority of the educators and employers still recommend that under normal conditions a student spend nine months in training in the university each year, and three months in training in an intensive laboratory course in the university or at work in industry in his particular field. If the student is going to reap the maximum benefit from his time spent in industry, the industries necessarily will have to assume a much greater responsibility for his training on the job than they have accepted in the past. The student's knowledge of the fundamental principles will prepare him to follow any engineering endeavor he may choose. The specialized fields of study should be deferred either for graduate work or for training on the job.

Success in the business and industrial world depends not on technical training alone but on many other factors. We have come recently to regard a proper mental attitude as an important contributory factor. It is the ability of the individual to adjust himself and demonstrate the so-called "will to do" that determines to a great extent whether or not he will be a success. As an aid to the proper mental state, health and endurance should be emphasized. We need men with surplus energy. The scope of physical education in institutions of higher learning should be enlarged to include physical fitness for each student.

A few universities give extensive training in the principles of executive and administrative work. The lack of such knowledge presents one of the greatest difficulties in the advancement of a man to positions of responsibility. A course in general executive work given in the last semester of the senior year by a thoroughly competent and practical teacher would benefit any graduate and enhance his value to a prospective employer.

Very few colleges give adequate training in what may be termed "human engineering" or human relationships. From the standpoint of the man as a potential executive who has to control other men, it is obvious that a knowledge of some of the basic principles of human relations would be of much value. Many educators agree that the humanities should make up approximately 20 per cent of the curriculum. In a number of colleges the professional studies monopolize almost the entire curriculum, which is usually already much overcrowded. Recently a few institutions have succeeded in the attempt to articulate the humanistic and technical courses into a logical series through which each student, during each quarter or semester, may be given a broad and well-rounded training in the social–humanistic courses. In many instances the humanistic courses are taught by practical teachers. This provision for an adequate number of humanistic courses in the engineering curriculum made it necessary to reduce the number of technical courses and also the contents of many of the courses. Careful scrutiny makes it possible to remove a lot of time-consuming frills from the curriculum, thus not only reducing the number of credit hours but in addition giving the student ample time to master fundamentals. The value of the intensification of courses is becoming more and more apparent.

In conclusion, it may be said that each student should be permitted to lay out, subject to the approval of his faculty adviser or the head of his department, a course of study for himself most in keeping with his goal and

aptitudes and with the industry or field of business activity in which he is most interested. If such a plan of study does not lead toward a degree, then let it lead toward a certificate. An opportunity to make major adjustments in programs of study should be given to those few geniuses or near-geniuses who are so concentrated that they cannot become interested to any great extent in anything but intensive, specialized subjects.

TEACHERS OF COLLEGE STUDENTS

No expense should be spared in obtaining teachers who can teach. Many faculties are made up of too many men primarily interested in abstract research and in writing papers and books (many of which are of little worth), who use their teaching only as a means of livelihood. It is not the intention of this article to underestimate the worth of research and writing; it is, however, endeavoring to call attention to the fact that in general those responsible for the recommendations of promotions and salary increases overemphasize degrees, research, and writing, and almost entirely forget the performance of good teaching for which the faculty members were primarily employed.

A professor who is also head of a department says:

"... For the past few years there has been considerable pressure on faculty people to do research and publish technical papers. This is probably being overemphasized. Our staff members should be good teachers and be able to inspire the students under them to do constructive work. At the same time a good teacher should be interested in research in his field, in making contacts in industry, and in writing such papers as he may feel will be valuable to other teachers or to the industry. The matters of research and publications are in themselves not important—the importance is that our teachers should be wide awake and active in their profession as well as in their teaching. Much can be done to raise the pay scale of teachers in order to attract an improved quality of personnel. I believe that faculty people should be encouraged to do outside consulting work, provided the time required does not interfere with college duties, both curricular and extracurricular, and also provided that they do not enter into unfair competition with existing personnel and agencies. It is also desirable that faculty people participate in industrial work during summer vacation. Staff members should have frequent discussion with students and spend a great deal of time in the counseling of students. The attitude should be that the professor exists for the students and not vice versa."

Those rare individuals who are good teachers, good researchers, and good writers are much too scarce, but every faculty should be made up of as many men of this caliber as possible for the benefit of the students, especially the graduate students.

An astoundingly large percentage of faculty members have not had any training in teaching methods; on the other hand, many with little teaching ability are holding teaching positions because they have taken the required hours of education. To improve methods in instruction, faculty members must be far better trained in teaching methods, and such training must be recognized as of equal importance with the proper mastery of the subject itself. Very few colleges make adequate provision for this training. Colleges have many so-called "teachers," but few *educators*.

A dean of freshmen in a nationally known engineering college says:

"Common complaints are that the instructor comes to class inadequately prepared and therefore does not cover the whole assignment; that he spends too much time on his own pet ideas; that he does not answer questions directly and clearly; that he takes too much time in answering the questions of the more aggressivr students and fails to cover all the material of the assignment; that he does not keep regular office hours and does not appear willing to give the students an adequate amount of time outside of the classroom; or that because of inexperience he is unable to express himself clearly before his classes."

Another common complaint from students is that many instructors have had a thorough academic training in a too-narrow field. They are mental giants in their particular grooves and "babes in the woods" when they wander beyond the walls of the rut. They know so much about their own subjects that their imaginations take them into the clouds, and they become impatient with students who do not understand such abstract teaching. Several deans have expressed their sincere interest in employing teachers with a broader training: for example, teachers in mathematics who have bachelors' degrees in science or engineering and doctors' degrees in mathematics; English teachers who have bachelors' degrees in engineering and doctors' degrees with a major in English, and so on. An English teacher with such qualifications would be invaluable to teach engineering students how to write technical reports. An employer of a large number of college graduates states:

"Report writing seems to be one of the 'bugbears' of engineering education. Most of the colleges, in my experience, require the boys to write upon certain forms of paper, in certain size folders, using stereotyped systems, a report of each individual experiment that is performed in the laboratory. I think we hear more growling from the young men about the long hours that they put in writing up this type of report than any other one thing. To me, they are right, and this is more or less a waste of time. If a boy could be taught to clearly outline in his own words, using his own form of presentation, the knowledge gleaned from a complete course involving a full term, he would gain infinitely more from this experience than from the submission of almost daily reports, as is now required. It is only by such expression in his own words that a boy will really remember the things that he has done in his school work, whether it be in the laboratory or in the classroom. I am convinced that many changes could be made in the whole problem of report writing."

If instructors are to keep abreast with the times, they should not only have a thorough academic and pedagogical training and experience, but also practical research and industrial experience in their own and allied fields. Some of the instructors might well exchange places for a time with men in the field. In this way the instructors would not only keep up to date on modern methods and developments, but they would have a keen appreciation of the students' problems after graduation, and new ideas could be brought into the college from industry. To maintain further these outside contacts,

each instructor who has an eager desire to grow mentally should be encouraged to attend worthwhile professional meetings and meetings of business organizations; to visit other universities, industries, and research laboratories; and to contact authorities in his field of work.

Genuine teachers are ready to give students friendly and helpful service at all times. Any instructor who enjoys offending a student for whom the hurdles may seem unusually high should hide his face in shame, yet how often instructors boastfully predict in public that one half of the class will fail by midsemester! Those same instructors are always looking for praise in order to bolster themselves for their own work.

The characteristics of instructors who are designated as good teachers have been summarized as follows:

Knowledge of subject—shown by ability to lecture without a slavish dependence upon notes; by accuracy of thought and conciseness of expression; by an up-to-date and thorough acquaintance, practical as well as theoretical, with the subject; and last but not least, by scholastic attainments

Effective presentation of subject—marked by clear, vivid, enthusiastic but at the same time methodical approach which holds the interest and undivided attention of students, combined with a human and patient persistence with mediocre and poor students

Personal qualities—wholesome attitude and a balanced philosophy of life, alertness, fair-mindedness, courtesy, humor, sincerity, tolerance, neatness—qualities that command admiration and respect and awaken a responsive spirit in the student

General knowledge—culture, knowledge of current events, being well versed in a number of subjects and realizing that his special subject is not the only one of importance in the course of study

Effective class management—good discipline, ability to make students work hard and like it, development of businesslike attitude toward classroom duties and initiative on part of student

Practical experience—commercial and industrial contacts that are an advantage in giving students an understanding of the conditions to be met after graduation and a valuable asset to the teacher in finding employment for students

NEED FOR RESEARCH

The present emergency has revealed the scarcity of men with creative ability. The future will demand extensive research in the solution of pure and applied scientific research problems. The graduate research students will find golden opportunities in the laboratories. Competent members of the staff should be encouraged to carry on research, for its performance brings to light creative ability and originality of thought among the members of the engineering staff and constantly changing student body, especially among graduate students.

The progress of the United States is now as never before depending upon American genius and American ingenuity, through the ever-opening avenues of scientific and inventive processes, to make the most of natural resources and the opportunities offered to a free people.

CONCLUSIONS

The present demand for trained engineers, trained workers, trained minds, skilled technicians, and for individuals with good health and surplus physical energy has placed a new and greater emphasis on education, its objectives, techniques, scope, functions, cost, and sources of revenue for its support.

The American educational system is primarily responsible for:

1. The maximum improvement of the physical, mental, and social aspects of the life of each citizen. This means co-ordination of the activities of the entire school system—elementary and secondary schools, vocational and trade schools, and colleges and universities
2. The provision for each individual to receive the opportunity for just as much education as will be of real benefit to him and as is economically justifiable
3. The teaching of fundamental principles so thoroughly that the individual will always be the master of them
4. The development, as far as possible, in each individual of such virtues as justice, honor, loyalty, honesty, respect, integrity, tolerance, thrift, co-operation, friendliness, and good will
5. Training in citizenship designed to improve the level of civic effectiveness
6. The formulation of concise definitions of the aims of each course offered and its relationship to the other courses in a program of study for an individual preparing for the different trades, occupations, and professions of life

After the aims and objectives of each course and program of study have been concisely and specifically formulated, the next major problem is to select programs which will be of maximum benefit to the individual, making him an asset to his community, state, and nation. A program of study should be selected which is in harmony with the student's mental and physical capacities, personality, mental attitude, character, initiative, and judgment. This might mean terminating study at the end of any quarter, semester, or year, and the receipt of a certificate instead of a diploma.

The admission standards for each program of study should be high, rigid, and adhered to, so that only qualified individuals are admitted, making it unnecessary to have a large percentage of failures. The student who satisfactorily completes a program of study which does not lead to a degree should be awarded an appropriate certificate of achievement. Each student should be made aware of the quality of the standards required of those to whom the schools, colleges, or universities award either certificates or diplomas.

State and national examinations should be provided, graded by outside committees, which would be more impartial and give a check on teachers as well as students. The instructor could then boast about the large percentage of his students who passed, instead of about the large percentage who failed his course under the present system.

The curriculum should be made up of fundamental subjects and fundamental principles, and each subject so taught as to create the habit of understanding thoroughly the subject matter and processes. Each student should be given maximum opportunity to develop

creative thinking. Irrelevant subjects should be deleted from the program of study, and each of the fundamental subjects revised to provide the individual with those fundamental principles that are of paramount value in the trade, vocation, or profession for which he is being trained. The University of Chicago has recognized the necessity for condensation and is now offering a bachelor of arts degree after two years of college work. Over 600 junior colleges in the United States will probably follow the example set by Chicago.

Specialization in professional undergraduate programs of study should be minimized; the graduate student, however, should be allowed to specialize in his chosen field. The student load should be reduced in order to allow sufficient time for a thorough mastering of each subject.

Provisions should be made for more after-college education, whether that be training on the job, graduate studies, or returning to the university after graduation for intensive or broadening courses.

No expense should be spared in obtaining teachers who can teach—individuals who know their subjects thoroughly and are imbued with enthusiasm and a keen interest in the training and development of students. Improved teaching should start with the elementary schools, but it should not end there. To secure it, we should offer greater incentives to those competent individuals who can teach and who are also interested in research and writing. Teachers should not be employed only because they have completed the required hours in education; they should be selected on the basis of mental and physical capacities, enthusiasm, knowledge of subject plus knowledge of related subjects, ability in and love of teaching, personality, sense of humor, interest in students, and character, supplemented by an adequate training in teaching methods. In this way we could disprove the old adage, "Those who can, do; those who cannot, teach."

The physical-plant facilities of a college—classrooms, laboratories, and offices—are of prime importance. During the past few years several colleges have made extensive additions to physical plants. The progressive colleges have desirable facilities and keep them in good condition. Making a greater and more effective use of such facilities is timely and necessary. Many educational institutions are now operating on a continuous wartime basis. This increased use of physical plant will in all probability be continued after the war.

The world crisis, bringing with it many economic and social problems, will have an unpredictable effect upon the colleges. The larger and more progressive institutions will readily adapt themselves to the changing conditions, while many of the smaller and less progressive are bound to face partial if not total collapse.

The colleges throughout the United States made enormous strides after World War I. The present war, too, will end; after which the colleges surviving this trial period will again be in a position to move forward with even greater advances than in the recent past. Because of improved physical-plant facilities in institutions of higher learning, and especially because of new laboratories, scientists have been able to raise the level of experimental inquiry in every region by discovering new methods of acquiring constructive knowledge, the lack of which has prevented rapid progress in the past, and a method of wisely applying knowledge once we have found it. Life always has been full of potentialities not fully developed for want of worthwhile channels of expression; such channels have been and will always be opened by the progressive colleges through the mastery of techniques.

Since the new frontiers of scientific research, invention, organization of production, and extension of service call for more and more college-trained men, there will always be a great need for progressive colleges, especially during the important postwar period of world-wide general reconstruction of an old world with a new society.

The educational system has been guided heretofore by precedent. College administrators and staff members have been imitators rather than initiators. The direction taken by the things that are now going on indicates the real condition toward which the world is moving. It also indicates clearly that the forward movement is the only one of promise and stability. The restudied, the reorganized, the readjusted, and the reconstructed colleges of tomorrow will point the way. Let's take "a backward look for a forward plan" by keeping the worthwhile changes forced upon us because of a world war.

Brazil's Hydroelectric Potentialities

Brazil is one of the richest countries in the world in potential hydraulic or water power. It has been estimated that the potential hydraulic power of Brazil is over 14,000,000 kw, and only about 739,000 has been utilized. According to statistics compiled by the World Power Conference, Brazil ranks fourth in hydraulic power. Russia ranks first, with 58,000,000 kw, the United States is second with 25,000,000, kw, and Canada is third with 19,000,000 kw. Statistics are based on discharge during a low water season.

The State of Minas Gerais has the largest number of hydroelectric powerhouses with the State of Sao Paulo second and the State of Rio de Janeiro third. However, the State of Sao Paulo has the greatest amount of power harnessed.

Brazil has one of the largest powerhouses in the world, located at Cubatao, near Santos, with a 308,000-horsepower installation. It is classified in eighth place according to world statistics on hydroelectric powerhouses.

Excerpt from an article, "Brazil—Arsenal of Strategic Materials," published in the February 21, 1942, issue of *Foreign Commerce Weekly*.

INSTITUTE ACTIVITIES

A Greeting to the Members of the Institute

First I wish to say a word of my appreciation of the great honor of being elected president of the Institute. The office is one of great distinction because it has been adorned by so many of the great names of our profession and also because the AIEE today is a great and very vital institution. Its greatness and vitality come not from size alone but are the result of the activities of thousands of members who express their interest in Institute affairs by carrying out its extensive program.

The honor of being president of the Institute comes to me at a time when the thoughts of all of us are overshadowed by the crisis in world affairs. I am sure that many of the members of the Institute have been thinking as I have of what is the place of the Institute in our world of today.

In many ways the war has greatly complicated our life but in one respect it is simplified. We have a simple criterion to apply to any proposed course of action—a criterion which is expressed in the motto that appears so often on the walls of the offices in Washington, "Will it help win the war?"

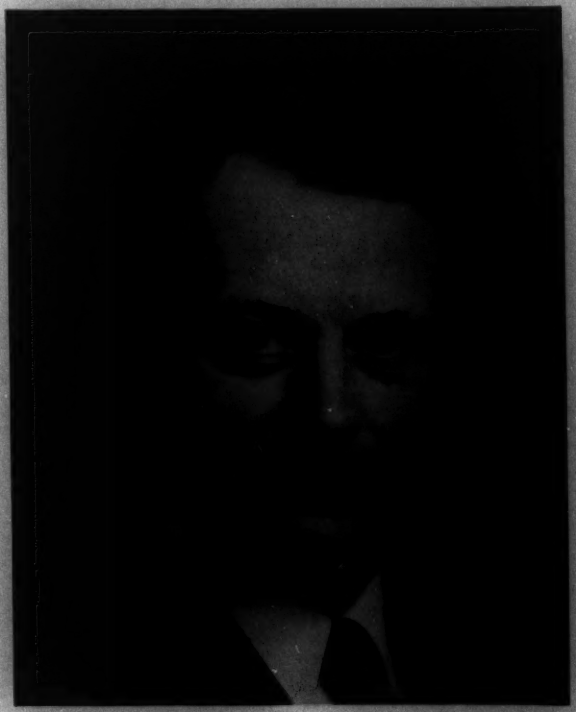
During the past year this criterion has been repeatedly applied by the board of directors and by the Institute committees in their planning of Institute activities. With the rapid change in conditions, it seems desirable now to take another look at the plans for all Institute activities for the coming year to see how they can be made most helpful to the war effort. This is being done by the committee on planning and co-ordination who will present their report at the August meeting of the board of directors. In the meantime at the June meeting the board approved recommendations of the technical program committee as to the type of papers to be presented at national meetings providing that all solicited papers shall be closely related to the war effort. These recommendations are reported elsewhere (p. 418) in this issue of *Electrical Engineering*.

While we believe these reviews will suggest ways in which the Institute program can be more closely allied with the war effort, it is not expected that they will cause revolutionary changes. The Institute is the great national forum for the discussion of advances in the electrical arts. Today much that we are doing is confidential and cannot be discussed. Some other topics are related to the war only remotely, and their discussion had better be postponed. Between these two classifications, however, there is a broad range of subjects which it is helpful to discuss at the present time. In this range we have an obligation to pass on information and experience which will help others to meet the responsibilities which the war has placed upon them. In our preoccupation with the urgent tasks of the day it would be easy to overlook this obligation. However, experience at the Chicago convention, where the program was unusually large and a great many of the papers were closely related to the war effort, shows that the members and committees are fully aware of this responsibility.

I should like to say a few words about another responsibility which it seems to me we have—not specifically as members of the Institute, but as members of the engineering profession. Of course, this is fundamentally a soldiers' war, like every war, but the overshadowing importance of production in this war has fastened public attention upon engineering in a way that perhaps has never happened before. As a group, engineers have a closer relation to the war activities than most groups of civilians, because of our close relation to production.

Therefore, we may be more influential than we realize in affecting the point of view of people in general on matters relating to the war. We ought to be able to help maintain those overtones of morale that come from having a real appreciation of the problem.

For example, what do we say in an unguarded moment about priorities and rationing? I suppose, with copper the scarcest of all scarce materials, we who are doing electrical engineering are affected as directly and as deeply by priorities and scarcities as any group of people in the



Harold S. Osborne, AIEE President 1942–43

country. Yet scarcities of things used by everybody are beginning to pinch people in general, and we know that necessarily those scarcities will become more widespread and more severe.

Now the man in the street must not fall into fallacy of thinking of these scarcities as due to the War Production Board or to priorities. We can help him always to bear in mind that the scarcities are due to Hitler. We know, and we can help him to realize, however much the overloaded machinery may creak, that the priorities system is doing a magnificent job, first in insuring that in so far as possible the war program gets the critical materials which it needs, and second in softening the impact of these scarcities upon our lives.

Another way in which I think we can help is by dampening undue waves of optimism or of pessimism with each minor swing of the fortunes of the struggle. While only the Army and the Navy can fully realize the immensity of the job before them, surely we, who are close to the production problem, have enough appreciation of the long sustained effort which is necessary to realize the importance that this effort should be not slackened by undue overconfidence, or by discouragement.

Finally, one more way in which I think we can help is to help maintain the long-range point of view. At the present time all our efforts must be concentrated on winning the war. But after the war is won, we must win the peace. That will mean answering a host of very difficult questions—economic questions, as Past President Prince has brought out so well in his talks on economic readjustments after the war, and international questions relating to reconstruction, and to the maintenance of peace.

It is clear that to get the correct answer to all of those questions will take the utmost that all of us have of wisdom and character. It is too early now to solve those problems. We have another task before us. But as we concentrate our efforts on the immediate task of winning the war, let us jealously guard our ability to take a long-range view and to make an unimpassioned analysis of facts. In all we do, let us hold this ideal before us so that we will be strengthened for these other and perhaps even more difficult tasks that lie ahead.

H. S. Osborne

Schedule of Events

Wednesday, September 9

9:00 a.m.	Registration (daily to 5:00 p.m.)
10:00 a.m.	Address of welcome. System operation session.
12:00 a.m.	Luncheon conference of National District, and Section Officers.
2:00 p.m.	Apparatus I session. Student technical session.
7:30 p.m.	Presidents reception and dinner.

Thursday, September 10

10:00 a.m.	Apparatus II session.
12:00 a.m.	Luncheon conference for students and Branch counselors.
2:00 p.m.	Student technical session. Golf competition for John B. Fisken cup.
9:00 p.m.	Dance

Friday, September 11

10:00 a.m.	System planning session
12:00 a.m.	Joint luncheon with Vancouver Electric Club.
2:00 p.m.	Selected subjects session.

Pacific Coast Convention Program Will Stress Power for War

Arrangements are in progress for the program of the Pacific Coast convention, which will be held in Vancouver, B. C., September 9–11, 1942. Convention headquarters will be in the Hotel Vancouver.

To aid the war effort the local technical program committee is developing a program of a practical rather than a theoretical nature. Most of the technical papers will deal with the problems of power supply and the protective equipment used on power systems and in industry. Tentative plans include six sessions on the subjects of system operation, apparatus, system planning, and selected subjects.

Two student sessions will be held, in which it is expected papers will be presented by the students. In addition, a dinner and conference will be held for all students and Branch counselors of Districts 8 and 9.

As is to be expected, the entertainment will be mainly in the evenings. However, there will be an opportunity for sightseeing, with entertainment for the visiting women. One of the afternoons will be devoted to the annual golf competition for the John B. Fisken cup.

ADVANCE REGISTRATION

Members who receive an advance registration card with the mailed announcement of the convention should register in advance by filling in and returning the card promptly. This will permit the committee to have badges ready and prevent congestion at the registration desk upon arrival. A registration fee of $2 will be charged all nonmembers except Enrolled Students and the immediate families of members.

Hotel reservations should be made by writing directly to the hotel preferred.

The personnel of the 1942 Pacific Coast convention committee making the arrangements was announced in *Electrical Engineering* for July, page 358.

Pacific Coast Convention

Wednesday, September 9

10:00 a.m. System Operation Session

42-146. A Practical Discussion of Problems in Transformer-Differential Protection. **P. W. Shill**, British Columbia Electric Railway Co., Ltd.

42-153. Three-Winding Transformer Ring Bus Characteristics. **G. W. Bills, C. A. MacArthur**, Bonneville Power Administration

CP.* Automatic Tie Line Load Control Application to the Northwestern Electric Company's System. **Owen W. Hurd**

2:00 p.m. Apparatus I Session

42-157. Some Air-Blast Circuit Breaker Installations in Canada. **H. W. Haberl**, Montreal Light, Heat, and Power Consolidated, and **R. A. Moore**, English Electric Company of Canada, Ltd.

42-155. Design and Operation of High-Voltage Axial Air-Blast Circuit Breakers. **Armin K. Leuthold**, Brown Boveri and Swiss Electric Company of Canada, Limited

42-148. Design, Manufacture, and Installation of 120-Kv Oil-Filled Cables in Canada. **D. M. Farnham**, Montreal Light, Heat, and Power Consolidated, and **O. W. Titus**, Canada Wire and Cable Company, Ltd.

● PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in this program may be obtained as noted in the following paragraphs.

● ABSTRACTS of papers appear on pages 433–4 of this issue.

● PRICES and instructions for procuring advance copies of these papers accompany the abstracts. Mail orders are advisable, particu-

42-151-ACO.† Some Canadian Developments in Relays and Relay Applications. **E. G. Ratz**, Canadian Westinghouse Company, Limited

Thursday, September 10

10:00 a.m. Apparatus II Session

42-118. Ignitron Rectifiers in Industry. **J. H. Cox** and **G. F. Jones**, Westinghouse Electric and Manufacturing Company

Engineer's Part in Solving Wartime Problems Featured at 1942 Summer Convention

Any lingering questions as to the value of or interest in AIEE convention programs and the opportunities offered thereby for the first-hand discussion of wartime engineering problems should be dissipated conclusively by the results of the recent summer convention in Chicago. As at the recent Northeastern District meeting at Schenectady, N. Y., the attendance set records for recent years, and participation in the various discussions and conferences was active.

As in the past years, at the technical sessions, which in many cases were keyed to specific engineering problems arising from the war production program, technical problems were discussed and new developments in engineering design and application were disclosed. Among the significant features of the non-technical meetings were the address, "Democracy in Its Struggle Looks to the Engineer," presented at the annual meeting by D. D. Ewing, head of the school of electrical engineering at Purdue University, and a challenge to the postwar engineer, "The Engineer's Last in a Postwar World," by AIEE President Prince, vice-president in charge of application engineering, General Electric Company.

This year's convention, at the Drake Hotel, June 22–26, was the 58th annual summer convention of the Institute and the fifth to be held in Chicago. (Others—1933, 1924, 1911, and 1892.) The total verified registration of 1,179 is of record proportions, having been exceeded only twice in the history of AIEE summer conventions. An analysis and comparison of registration figures are given in the accompanying tabulations.

Attendance at technical sessions ranged from 40 to 200, averaging more than 100 at a session. Conference sessions were attended by an average of over 55. Interest in AIEE affairs was evidenced by an attendance of 200 at the annual meeting, and the appeal of general topics was indicated by an attendance figure of 300 for the general session. Such reports of technical conferences as were available appear elsewhere in this issue, as also does the substance of the annual conference of officers, delegates, and members.

Annual Business Meeting

The annual business meeting of the American Institute of Electrical Engineers convened at 10 a.m. on Monday, June 22, 1942, in the ballroom of the Drake Hotel in Chicago, Ill. H. B. Gear welcomed those present and introduced D. D. Ewing, as principle speaker. Following his address, the official business session was convened by President Prince, who called upon H. H. Henline, National secretary, to present high lights from the current annual report of the board of directors. This report was published in full in the July 1942 issue of *Electrical Engineering*, pages 368–81. Mr. Henline also reported on the activities of the Sections and Branches, concerning which a report was published in the June 1942 issue of *Electrical Engineering*, pages 322–3.

SECRETARY'S REPORT

Among the salient points of the annual report as given by Mr. Henline were the following:

During the current administration year the number of AIEE Sections reached a total of 72. The board of directors last January decided to assign to the existing Sections all remaining parts of the United States so that members in all areas of the United States are now included in some Section. AIEE membership, he said, reached a total of 18,094 at the end of the fiscal year, and a total of 19,065 on the first of June. These figures are far higher than any membership before the depression.

1942–43 OFFICERS ANNOUNCED

Following the reading of the annual report, Mr. Henline gave the report of the committee of tellers, including a complete list of the officers of the Institute for the administration year beginning August 1. Essential substance of this report was published in the July 1942 issue of *Electrical Engineering*, page 358. As is customary at this point in the annual meeting, President Prince welcomed Doctor H. S. Osborne of the American Telephone and Telegraph Company as president-elect of the Institute for the year 1942–43.

TREASURER'S REPORT

W. I. Slichter, treasurer, summarized and confirmed the official report of the auditors, which has been printed as a part of the annual report of the board of directors. The gross income of the Institute for the fiscal year ending April 30, 1942 was $344,901.81 as compared with $318,684.13 for the previous year, while expenditures for the past fiscal year amounted to $320,748.82 as compared to $299,222.81 for the previous year. Surplus for the year totaled $24,262.06. The total reserve, capital fund for the fiscal year ending April 30, 1942, Mr. Slichter reported to be $251,211.20 in comparison with the previous year's amount of $220,255.69. In these days, he pointed out, the investment of such funds is a difficult matter, and the finance committee has found it advisable to keep a certain amount of these funds in a liquid condition so that the Institute may be prepared later for the change from war to peace. Therefore, the committee has kept in quick assets, short-term government securities amounting to $119,534.94 and cash in banks amounting to $35,520.87, giving a total of $155,055.81.

PRIZES AWARDED

P. L. Alger, chairman of the committee on award of Institute prizes, announced the winners of national prizes awarded for papers presented during 1941, and President Prince presented the awards. The report of the committee on the award of Institute prizes appears as a part of the report of the board of directors (see *EE, July '42, p. 377*). This is further supple-

Technical Program

larly from out-of-town members, as an adequate supply of each paper at the convention cannot be assured. Only numbered papers are available in pamphlet form.

● ALL PAPERS regularly approved by the technical program committee ultimately will be published in Transactions; many will appear also in Electrical Engineering.

42-138. Electrical Equipment for Large Electrochemical Installations. **T. R. Rhea** and **H. H. Zielinski**, General Electric Company

42-156. Interim Report on Guides for Overloading Transformers and Voltage Regulators. Transformer subcommittee of committee on electrical machinery.

CP.* An Analysis of the Allocation of System Investment Charges to Kilowatt and Kilovar Requirements. **J. W. Butler**, General Electric Company

Friday, September 11

10:00 a.m. System Planning Session

42-150. Power-System Interconnection in Quebec. **W. R. Way**, The Shawinigan Water and Power Company

42-149. Method for A-C Network Analysis Using Resistance Networks. **Waldo E. Enns**, Portland General Electric Company

42-158. Inverse Functions of Complex Quantities. **H. B. Dwight**, Massachusetts Institute of Technology

2:00 p.m. Selected Subjects Session

42-152. History of A-C Wave Form, Its Determination and Standardization. **Frederick Bedell**, R. C. Burt Laboratory

42-147. A New Single-Pole Service Restorer. **E. E. Tugby**, Pacific Electric Manufacturing Corporation

42-154. Application of Vacuum-Tube Oscillators to Induction and Dielectric Heating in Industry. **J. P. Jordan**, General Electric Company

*CP: Conference presentation; no advance copies of papers available; not intended for publication in *Transactions*.

† ACO: Advance copies only available; not intended for publication in *Transactions*.

Analysis of Registration at 1942 Summer Convention, Chicago, Ill.

Classification	Districts										Totals
	1	2	3	4	5	6	7	8	9	10	
Members	70	149	71	24	473	7	34	9	9	9	855
Men guests	11	17	6		106	2	4	1			147
Women guests	9	27	19	9	97	3	8	2	2	1	177
Totals	90	193	96	33	676	12	46	12	11	10	1,179

mented by information on District prize awards published on page 360 of the July issue of *Electrical Engineering*.

LAMME MEDAL TO F. E. RICKETTS

The 1941 AIEE Lamme Gold Medal was awarded to Forrest E. Ricketts (A'16) vice-president of the Consolidated Gas, Electric Light, and Power Company of Baltimore, Md. On behalf of the Lamme Medal committee, C. A. Powel outlined the basis of the award and gave a brief address on some of the outstanding points of the career of the donor, Benjamin Garver Lamme.

Nicholas Stahl, chief engineer of the Pennsylvania Power and Light Company, introduced the Medalist Ricketts, giving an account of his life and accomplishments, to which Mr. Ricketts responded, after presentation of the medal by President Prince. Text of these addresses appear on pages 397–401 of this issue.

Other Convention Features

An unusual feature of the 1942 summer convention was a special AIEE wartime broadcast over the Columbia Broadcasting System from Chicago on the evening of June 25, bringing together Brigadier General Donald Armstrong of the United States Army Chicago Ordnance District, D. C. Prince, AIEE president, and H. B. Gear, general committee chairman of the convention and vice-president of the Commonwealth Edison Company, in a program which was designed to convey to the public the vital part of American industry the battle of production and especially to show how electricity is fighting the war.

ENTERTAINMENT AND SPORTS

Successfully carrying out a feature that has proved effective at some previous summer conventions, the Chicago Committee arranged for a preconvention reception for early arrivals. This affair was held in the Drake Hotel Sunday evening, June 21, beginning at about 6 p.m. and lasting until after 8 p.m. Refreshments were served informally, buffet style, with members of the ladies' committee acting as hostesses. The attendance exceeded 100.

The president's reception was held in the Tower Room of the Drake on Monday evening, June 22, and was followed by a dance, sponsored by the Chicago Section, in the Gold Ballroom.

Another high light of the war-limited entertainment features of the summer convention was the Tuesday evening affair held at the Lake Shore Club. Located just three short blocks from the Drake Hotel, convention headquarters, the Lake Shore Club was easily reached on foot, thus avoiding transportation difficulties. The evening's affair started with the progressive serving of a substantial buffet meal to the 500 persons attending from about 7 p.m. until after 9 p.m. Entitled "Beaches and Boulevards of Central and South America," the evening's program featured double-header, all-star programs, carried on in parallel so as to divide the crowd and avoid congestion. The major feature comprised an hour-long revue including clowning, tight-rope performers, and musical variety, all of exceptional excellence. The minor feature embraced a very high-quality aquatic display in the luxurious pool of the Lake Shore Club featuring various individual stars and teams of highly proficient water-ballet performers, principally of the Lake Shore Club. In general the evening was reminiscent of the highly successful Hart House social evening staged on the grounds of the University of Toronto by the Toronto convention committee in 1941, and was equally highly spoken of as the high spot of the convention's entertainment features.

Because of wartime curtailment it was not possible to arrange for the customary technical inspection trips. Sports events this year were limited to the annual golf tournaments for the Mershon cup and the W. S. Lee trophy, both of which were won by H. G. Schultz (A'26) supervising field engineer of the Commonwealth Edison Company, Chicago.

Recent Summer Convention Attendance

1942	Chicago, Ill.	*(5)	1,179
1941	Toronto, Ont., Can.	(10)	1,203
1940	Swampscott, Mass.	(1)	1,014
1939	San Francisco, Calif.	(8)	940
1938	Washington, D. C.	(2)	825
1937	Milwaukee, Wis.	(5)	1,067
1936	Pasadena, Calif.	(8)	715
1935	Ithaca, N. Y.	(1)	904
1934	Hot Springs, Va.	(4)	351
1933	Chicago, Ill.	(5)	968

* District numbers in parentheses.

Annual Conference of Officers, Delegates, and Members Held at Chicago

The annual conference of officers, delegates, and members was held on the afternoon of June 23, 1942, during the recent AIEE summer convention at Chicago, Ill., with M. S. Coover, chairman of the Sections committee, presiding. A report on the Engineers' Council for Professional Development was a feature of the meeting, which opened with a talk by AIEE President D. C. Prince. Reports were presented by the chairmen of the Sections committee and the technical program committee, and the meeting concluded with extensive open discussion on two main themes—the timely subject of Section activities to aid the war effort, and the perennial topics of attendance at Section meetings and relations between Sections and Student Branches.

President Prince presented a brief résumé of impressions that he had gained from his tours of visits to Sections and Branches during the past administrative year. He emphasized briefly the dual nature of the job now facing engineers as a group: (1) the technical and operating problems of industry in its concentrated war effort; (2) the responsibility as individuals to take part in local affairs to help provide the stable guidance needed, at the same time to give thought and attention to the need for constructive planning for the future to be sure that we preserve the goal for which the nation now is fighting.

Vice-Chairman and Secretary W. B. Morton reported briefly on the actions and recommendations of the Sections committee meeting held during the 1942 winter convention (*EE, Mar. '42, p. 161*).

Chairman P. L. Alger of the technical program committee called attention to the desirability of directing the efforts of the Institute—local Sections, technical committees, District meetings, national conventions—toward maximum contribution to the war effort. He summarized the proposed plans and policies of the technical program committee for the coming year as follows:

1. All technical programs and papers should be closely related to the war effort. The chairmen of technical committees will be expected to submit evidence of the value of all recommended papers in this connection before their programs can be approved.

2. In general, programs should present practical recommendations, or results of experiences, in the form in which they may be of most use to those engaged in war production or planning.

3. To supplement restricted attendance at conventions, conferences may be held at centers of specialized activity, whereby those attending may see the work in which they are interested, and the group as a whole will have the least traveling to do.

4. Papers of insufficient value to the war effort to warrant acceptance at this time, and papers which cannot be published for censorship reasons, will be held in abeyance for presentation and publication after the emergency.

SOUTH AMERICAN SECTIONS CONSIDERED

Chairman Coover reported that within the past year all remaining territory within

the continental United States had been assigned to Sections. This is an objective toward which the Sections committee, following out various recommendations from the annual conferences of officers, delegates, and members, had been working for some time. Thus, any new Sections formed hereafter will have to draw their territory from existing Sections, and proposals of necessity will be considered accordingly.

Chairman Coover reported also that currently there is under way an investigation into the possibilities of forming one or more Sections in other countries of the Western Hemisphere in which there are substantial numbers of AIEE members. In addition to the three Sections in Canada (Toronto, 1903, Vancouver, 1911, Saskatchewan, 1925), and the Mexico Section (1922), there are at present concentrations of members in Cuba, Argentina, Brazil, Chile, Columbia, and Venezuela that suggest the possibility of strong local Sections, depending entirely, of course, upon local interest and local option. The Sections committee currently is corresponding with members in these areas, and expects reasonably soon to be able to formulate specific recommendations based upon suggestions received from these members. The initial response is enthusiastic and it seems reasonable to expect some definite developments, perhaps within the next year.

ECPD EXPLAINED TO DELEGATES

An excellent and illuminating exposition of the objectives and procedures of Engineers' Council for Professional Development was given in a report prepared by James F. Fairman, New York, N. Y., one of the AIEE representatives on ECPD Council. Mr. Fairman's active and constructive participation in ECPD affairs on behalf of AIEE has placed him in a position to give the clear and compelling view of ECPD that is provided in the report published in full elsewhere in this issue. In Mr. Fairman's absence, Vice-President E. S. Lee, another active AIEE representative on ECPD, very effectively and inspiringly presented the report.

SECTION ACTIVITIES IN THE WAR EFFORT

Various suggestions were made concerning the methods and procedures for making AIEE Section meetings more effective, both to members and in the general pursuit of the nation's war effort.

A. E. Knowlton, speaking on behalf of AIEE committee on industrial power applications, urged local Sections to give attention to the problems of industrial engineers and, wherever feasible or productive, to hold special meetings, round-table conferences, or clinics, on electrical problems incidental to the application, operation, and control of equipment in war industries that do not have the benefit of self-contained engineering organizations. This proposal was specifically endorsed by Chairman Alger of the technical program committee.

Chairman-Elect Clyde C. Whipple of the New York Section briefly reviewed the experiences of that Section in its collaboration with other engineering groups and the War Production Board in the holding of a recent "production clinic" in Newark, N. J. Attendance at that conference was developed through the medium of notices sent to the membership of the New York metropolitan Sections of the several national engineering societies, with the result that primarily the engineers from these societies attended, and not enough of the engineers from local small industries, toward which the conference was specifically aimed. Mr. Whipple reported that the New York Section in collaboration with the local sections of other societies was contemplating the establishing of a joint board of engineering consultants, whose services would be available to representatives of small industry as a contribution of the national engineering societies in that area. This project is to be considered further during the coming year.

Methods of stimulating attendance at meetings of local Sections ranged all the way from door prizes to better programs. Representatives from some Sections reported that they had had satisfactory results from such artificial stimulants as door prizes. Other Section representatives reported that they had been able to develop and maintain satisfactory attendance by a schedule of meetings programs related to local problems of interest to engineers. Several Sections do not try to draw all members to all meetings, but concentrate in each meeting on a technical subject of some direct interest to one group of members, thus enabling more penetrating and effective treatment of the selected subject matter; other groups are served at different times during the year by similar concentrations on other topics. Specifically the Pittsburgh Section reported such a plan for the coming year.

Chairman H. W. Bibber of the committee on Student Branches challenged each local Section to make special effort to cooperate with local Student Branches during the ensuing year. With special reference to the "fellowship dinners" which a good many Sections hold once each year as host to local Student Branches, Professor Bibber pointed out that several Sections had greatly enhanced the value of such contacts by arranging for an individual Section member to be the individual host of some student member and limiting tables to three or four such pairs. Professor Bibber urged that this practice be followed by more Sections as compared with the more common practice of inviting students to attend and allowing them to stick together all evening as a relatively isolated group.

A particularly valuable suggestion was made by the representative of the Washington Section who pointed out that one secret of the strength of the Washington Section lay in its definite arrangements for giving a maximum number of Section members something definite to do. This lightens the burdens of committee memberships and stresses the valuable idea of individual participation.

Chairman Coover urged all Sections to make some special and appropriate arrangement at least once each year to give direct and specific recognition to: (1) Enrolled Students who complete their transfer to the grade of Associate; (2) members who complete their transfer to a higher grade of membership.

Aid to ECPD in Promoting Guidance for Young Engineers Discussed at Chicago

At the AIEE summer convention conference of officers, delegates, and members on June 23, 1942, Chicago, Ill., "What the Sections Can Do to Assist ECPD" was the subject of an address by J. F. Fairman (F'35) AIEE representative on Engineers' Council for Professional Development. The essential substance of the talk, which was delivered by E. S. Lee (F'30) in the absence of Mr. Fairman, is as follows:

Engineers' Council for Professional Development is a conference of engineering bodies organized to enhance the professional status of the engineer through the cooperative support of those national organizations directly representing the professional, technical, educational, and legislative phases of an engineer's life. The participating bodies are the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the American Institute of Chemical Engineers, the Society for the Promotion of Engineering Education, the National Council of State Boards of Engineering Examiners, and The Engineering Institute of Canada.

WHAT ARE ECPD'S OBJECTIVES?

The purpose of ECPD as quoted from its charter, "is the enhancement of the professional status of the engineer. To this end it aims to co-ordinate and promote efforts and aspirations directed toward higher professional standards of education and practice, greater solidarity of the profession, and greater effectiveness in dealing with technical, social, and economic problems. "An immediate objective . . . is the development of a system whereby the progress of the young engineer toward professional standing can be recognized by the public, by the profession, and by the man himself, through the development of technical and other qualifications which will enable him to meet minimum professional standards."

WHAT IS ECPD'S PROGRAM?

ECPD's program consists of four parts:

1. The development of further means for the educational and vocational orientation of young men with

Several widely separated geographical Districts of the Institute are represented in this group conferring informally at the AIEE summer convention at Chicago. Shown here are, left to right: Alexander Dorjikow (M'41), engineer, Bonneville Power Administration, Portland, Oreg.; A. C. Monteith (M'40), manager, industry engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; R. T. Henry (F'33), assistant chief electrical engineer, Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y.; C. F. Wagner (F'40), manager, central-station engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; J. R. North (F'41), electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich.

respect to the responsibilities and opportunities of engineers in order that only those may seek entrance to the profession who have the high quality, aptitude, and capacity which are required of its members.

2. The formulation of criteria for colleges of engineering which will ensure to their graduates a sound educational foundation for the practice of engineering.

3. The preparation of plans for the further personal and professional development of young engineering graduates, and also of those without formal scholastic training.

4. The development of methods whereby those engineers who have met suitable standards may receive corresponding professional recognition.

It appears necessary to emphasize this program because it seems clear to those who are connected most closely with ECPD's work that before Engineers' Council for Professional Development can accelerate its progress toward the objective stated in its charter, it is essential that not only the officers and boards but the rank and file of the constituent organizations understand much more fully than they have in the past what these objectives are and the importance of their achievement to the welfare of the engineering profession.

An astonishing number of people, including some comparatively close to the work, have felt that the most important activity and the only significant achievements of ECPD have been in connection with the accrediting program. Yet the charter clearly indicates other purposes and activities—relating to selection and guidance, professional training, professional recognition—and these are also actively pursued by standing committees. From the point of view of further advancement of the profession, and more important still, the welfare of the country, these other purposes and activities are in the long run unquestionably of equal importance with accrediting. Good students are not less essential than good schools. Hence, it seems necessary and desirable for the representatives of the participating bodies to conduct an educational campaign among their respective organizations, as one of the most important projects to be undertaken by ECPD.

AROUSING INTEREST OF AIEE

The Institute's representatives on ECPD have suggested that the way to achieve understanding of and active interest in the purposes of ECPD by the members of the constituent organizations is to have the local sections or chapters take an active hand; and that one way to bring this about is to have the whole matter, including a plan, discussed at this conference of officers, delegates, and members of the Institute who are among those responsible for Section activities, for if they understand the plan and are *convinced* of its value, something will come of it when they go back home. AIEE representatives on ECPD believe that the field in which the local Sections might become most active is that of selection and guidance. This work might be patterned along the lines of the procedures already developed in certain metropolitan areas in connection with the work of the ECPD committee on student selection and guidance. Once this is under way, a second step taken by a Section might be in relation to the work of the ECPD committee on professional training in helping young graduates to become appropriately oriented and active in their own professional development.

STUDENT SELECTION AND GUIDANCE

The ECPD committee on student selection and guidance endeavors to develop means for the educational and vocational orientation of young men with respect to the responsibilities and opportunities of engineers, in order that only those may seek entrance to the profession who have the high quality, aptitude, and capacity which are required of its members. This is a very tangible activity in which local Sections can participate. Many are already doing so.

Engineers in several localities have begun to realize the importance of student guidance, and those who have participated have been stimulated by the experience. The counseling of young aspirants for engineering training has a definite bearing on the future membership of the engineering profession and of engineering societies. It is also a civic service and is destined to pay real dividends in every community where it is given a fair trial. The organization of committees of engineers, representing all branches of engineering, to co-operate with high-school guidance officers is continuing slowly, but the results already obtained have been of such value that other communities should be encouraged to recognize and grasp this opportunity which is open to them.

A joint appeal was made to local sections of engineering societies supporting ECPD by the committees on professional training and on student selection and guidance. Replies were received from 50 local sections and city organizations of engineers.

The following citations briefly set forth the experiences disclosed by the replies:

Sections of the leading engineering societies within the metropolitan area of New York, acting jointly, have the largest guidance program with fine support from the societies, the school authorities of greater New York, high-school boys, and their parents.

Requests to extend the program to neighboring areas have been made but lack of funds limits the distance to which speakers can be asked to go at their own expense. Neither expenses nor fees are paid for services. Approximately 100 engineers participated last year in visits to 25 high schools, and assisted 2,000 students in learning what engineering is and what it "takes." Some 5,000 additional boys attended of their own volition to hear the general talks which preceded the more intimate group discussions.

Baltimore, Md., originated some years ago a program of co-operation between education, industry, and engineering in which the Engineers' Club was a leader. The Baltimore committee not only has assisted in counseling in the high schools but has "examined critically the objectives and results of the city's vocational schools in the light of industrial needs." The committee also "instituted studies relative to available jobs and educational requirements, relations of one job to another, and a state-wide job-analysis survey." This constitutes constructive civic service.

In Atlanta, Ga., it has been the practice for engineers to speak to seniors in the secondary schools. It is reported that "a symposium is held and later those boys who are still interested are divided according to the branch of engineering in which they seem interested; representative engineers meet with each group giving information and advice. Individual interviews are then scheduled for those who desire them."

The Washington, D. C., section of The American Society of Mechanical Engineers favors a guidance program and adds, "Pre-engineering guidance is very important. Too many students of mediocre ability enter college for engineering training. At least half of them should enter good trade schools instead."

Another comment: "Guidance should be down to earth. Boys want to know about salaries, prestige, where they can get to, what various types of engineers do. One of the main features of the program should be to guide boys away from engineering who don't belong."

The Engineers' Club of Dayton, Ohio, has sponsored guidance programs. Cincinnati, Ohio, is well served by engineer counselors. Exceptional programs are supported by The Engineering Society of Detroit; by the Colorado Engineering Council which organizes and supervises guidance programs in Denver and other cities. The Nebraska Engineering Society and the Engineers' Club of Omaha (Nebr.) have continued their efforts. The Iowa Engineering Society has continued its unique plan of bringing each high school into contact with the society and state institutions teaching engineering.

Birmingham, Ala., has an able committee of industrial leaders and educators which attempts to provide the leading cities of Alabama with effective engineering guidance. Such generous and enthusiastic civic service deserves recognition.

Memphis, Tenn., and the states of Mississippi and Louisiana have shown an interest in the organization of guidance groups.

St. Louis, Mo., through Doctor Jules Bebie, consulting chemical engineer, has begun to offer additional facilities besides those offered by the Young Men's Christian Association.

The Engineering Institute of Canada has been organizing guidance for some time and is now publishing a booklet of about 30 pages entitled, "The Profession of Engineering in Canada—Information for Prospective Students." This booklet includes sections on engineering in Canada, and on each of the leading subdivisions of engineering. H. F. Bennett, the chairman of the committee which prepared the booklet, is a member of this committee of ECPD.

Obviously the engineering societies, national, state and local, are one of the best means of reaching the high-school boy who is considering engineering as a lifework. These agencies are a first line of offense for prosecuting the purpose of guidance. Hence we make our appeal to you to organize a guidance committee, if you have not already done so, and if you have, to expand and carry on this work as vigorously as possible. This work cannot reach out into the smaller communities without the aid of local groups of practicing engineers. Michigan, Nebraska, Colorado, Iowa, and Alabama are carrying on statewide activities. This is the ultimate goal.

GUIDANCE MANUALS ARE AVAILABLE

ECPD has published a booklet entitled "Engineering as a Career" which is used in these guidance activities. This booklet was prepared particularly for young men, parents, teachers, and others interested in educational guidance to give something of an introductory insight into the profession of engineering. Copies have been widely distributed to high schools, local engineering organizations, and others who are or should be interested in guidance activities. Each section should have received one but if it has been lost or mislaid, another copy can be obtained from AIEE headquarters. Additional copies are available at a price of 10 cents per copy or $7.50 per 100 copies. A second manual intended to guide the guiders has been used in mimeograph form for several years. It is now being printed and will shortly be available. This manual describes the methods which have been found most effective. Copies of this may also be obtained from AIEE headquarters.

PROFESSIONAL TRAINING

Work in the field of professional training is not so far developed as that of student guidance but a good start has been made both by the ECPD committee and certain local groups. E. S. Lee is now chairman of ECPD's committee which is studying and promoting this project. This committee has just begun work on a manual similar to the booklet, "Engineering as a Career," but intended to give the young engineer guidance during his formal educational period and during the apprenticeship or interneship that follows immediately thereafter.

Additional activities of the ECPD committee on professional training include plans to make engineering periodicals available to members of constituent societies who are in the Service by having the publications sent to regularly established Service libraries, either direct from the society, or from individual members. The latter is the plan of the AIEE (see *EE, July '42, p. 359*).

SUGGESTIONS FOR LOCAL ORGANIZATION

In closing I should like to make a few suggestions which may be helpful to those who have started or who are planning to start some local activity in these two fields. In the first place, ECPD is not organized and should not be organized to enter the local field. There are quite enough local engineering organizations already. However, the committees of ECPD will help in any way they can by answering questions, by supplying information as to the experiences of other local groups, and by making suggestions based on their observations. Requests for information may be addressed to the chairman of any ECPD committee or to H. H. Henline, AIEE national secretary, who is also secretary of ECPD. He will see that such requests are directed to the proper committees.

Co-operation with the other local engineering groups is important. On the other hand, failure to arouse their interest should not prevent starting this activity. Invariably they will be glad to join as soon as the full significance of the endeavor becomes clear to them.

In the case of guidance activities it is vital that the co-operation of the school authorities be obtained. It should be made clear to school superintendents, high-school principals, and school guidance counselors that you have nothing to sell, that you are not agents for a particular college, that you are not trying to interfere with their work, but that you will be glad to assist their students in making a wise choice of vocation by giving information, answering questions, and helping each boy make an intelligent measure of his adaptability, interest in, and preparation for an engineering career. No definite rules can be laid down. Each local situation must be handled on its merits and according to its needs. The type of organization and method of operation must be adapted to the local situation. In the work that has been done thus far, the local Sections of the Institute have in general been leaders. May they continue so.

AIEE Participation Urged for WPB Industrial Salvage Program

Co-operation by the Institute as an organization and by Institute members as individuals in the industrial salvage program set up by the War Production Board was solicited by George Sutherland of the WPB Bureau of Industrial Conservation, speaking at the general session on June 25, 1942, of the recent AIEE summer convention at Chicago, Ill.

As an organization, operating through its committees and especially through its local Sections, AIEE should co-operate in and emphasize the importance of the salvage program of the WPB, stimulating it and improving its effectiveness in every way in every possible locality, Mr. Sutherland declared. As individual members of the AIEE, every person should make himself a committee of one to promote the effectiveness of the salvage program, in his business connections as well as in his home and community connections and activities.

Describing the organization of the Bureau of Conservation, Mr. Sutherland explained that originally it included five sections, three of which were concerned with conservation of new materials, through simplification of designs, standardization, and substitution, and two sections concerned with salvage—one handling the general salvage program, and the other with industrial salvage only. He described the general salvage section as "the Hallelujah Chorus—the group that works on the general public, to induce people to save and contribute small individual quantities, which in the aggregate make a substantial contribution to the amount of material required." This section handled the drive for scrap rubber. A special division of this section has been set up to handle specialized projects that require elimination of legal entanglements, such as taking up rails no longer used by street railways, and another special division is concerned only with "automobile graveyards."

The industrial salvage section, Mr.

Sutherland explained, operates in two ways: (1) through industrial centers, by sending its staff members to organize salvage operations throughout a whole industrial community; and (2) vertically in individual industries, by having one man in charge of organizing salvage throughout an entire industry. He reported progress by both methods. "The scrap is coming in, and the work of making people scrap-conscious is being effective," he declared.

In response to a question from President Prince concerning the possibility of a formula for determining under what conditions the machinery normally required for industrial peacetime production but now standing in storage at most industrial plants should be classified as scrap and turned in or held in reserve for postwar production, Mr. Sutherland pointed out that no formula was possible. He suggested that where any such machinery had been idle for even as little as five years, or where there was any likelihood at all of postwar changes in model or design of product, the machinery in question would be more valuable to the nation if turned in for scrap now and replaced after the war with modern equipment adapted to the circumstances that then will prevail.

INDUSTRY FORMS SALVAGE COMMITTEE

Formation of the American Industries Salvage Committee, representing groups of leading industrial concerns who are working with the Conservation Division of the WPB to help speed the collection of vital scrap materials, has been announced by Robert W. Wolcott, chairman of the group and president of Lukens Steel Company. The work of the committee, backing up a broad advertising program, will be: (1) to reach every manufacturing and business firm in the nation to emphasize the absolute necessity of getting scrap on the way to the production line; and (2) to get businessmen cooperating with the local salvage committees of the WPB already set up in 12,000 communities. The activities of the committee will be closely co-ordinated with the present intensified scrap collection drive of the WPB, according to Mr. Wolcott. In this connection, the committee is underwriting the cost of an extensive national advertising campaign approved by the WPB, with a number of major industries underwriting the costs. The advertising being carried on in newspapers, magazines, farm and trade papers, and on the air, focuses the spotlight of public attention upon the need for iron and steel scrap, nonferrous metals, rags, burlap, rubber, tin cans (in some localities), waste cooking fats.

Supplementing contacts with industry already established by the Industrial Salvage Division of the WPB, the American Industries Salvage Committee will make a direct approach to individual industrial concerns, working through industry chairmen who are now being appointed. Leaders in fifty industries are being asked to serve as chairmen for their respective trades in a broad effort to see that every company appoints a salvage manager with authority not only to clean out production scrap, but also to junk obsolescent equipment.

Organization and Management of Engineering Described at Unusual General Session

An innovation in Institute convention programs which attracted marked interest was the general session of the summer convention Thursday morning, June 25, 1942, on the subject of "The Organization and Management of Large-Scale Engineering Works" at which President D. C. Prince presided. Reflecting the increasing degree to which engineers are taking on managerial functions, various aspects of engineering organization were presented by executives representing communications, electrical manufacturing, and public utilities.

M. R. Sullivan, vice-president, American Telephone and Telegraph Company, New York, N. Y., the first speaker in this symposium pointed out that the glamour associated with the recent and startling developments of science has kept the public from realizing that "until a competent organization takes the results of scientific research and translates them into products and services, the public gets little good from the research." Mr. Sullivan emphasized, as did the other speakers, the importance of administration and executive direction, calling attention to the fact that in the Bell System one out of every eight employees occupies a supervisory position.

Organizational and personnel policies of the General Electric Company were described by R. C. Muir (F'36) vice-president of that company, Schenectady, N. Y., who said the aim had been to achieve both directness of action by the whole organization and freedom of action for individual engineers and engineering groups, and to do this without conflict. Among the principles he mentioned as underlying the organizational setup were: that form of organization should be subordinate to personnel; that responsibility should always carry corresponding authority; that a "runner up" should always be available for each important position, so that no unexpected loss of one person can seriously embarrass or disrupt operations; that organization and development of personnel should be specifically planned, looking ahead for 15 years or more.

The relation of engineering management to the over-all management of a large public utility was discussed by H. B. Gear (F'20), vice-president, Commonwealth Edison Company, Chicago, who cited his experiences as a young engineer in helping to bring order out of the chaos of conflicting systems and methods at the beginnings of utility development, as an example of the contribution engineering makes to the management of an enterprise. He stressed the engineer's need to see his own work in perspective, as part of the whole enterprise with which it is associated.

Essentially full text of the talks by Messrs. Sullivan, Muir, and Gear, and a résumé of part of the resulting discussion, follow.

The Organization of Large-Scale Engineering Work

M. R. SULLIVAN

"The road ahead is dim with the dust of battles still unfought but it is brighter than it would have been had our enemies not misjudged us and themselves, for when Hitler put his war on wheels he ran it straight down our alley. When he hitched his chariot to an internal combustion engine he opened up a new battle front—a front we know well."

These are the words of General Somervell, head of the Service of Supply of the United States Army. Mass production of machines on wheels and machines that fly and the stuff that goes in them—that, he says, "is right down our alley." We can beat the enemy at that.

What that statement means to me is that "the organization of large-scale engineering work" is America's choice of a battle front. On that ground we are called to meet our enemies, and it is fortunate that this is true, for the freedom of the world depends on our acceptance of this front and our success on it.

The thing that distinguishes America on this front is its capacity for organization. The capacity to produce is not entirely a matter of raw materials and skilled labor. Other nations have as much or more of these than we have. Our ability to roll out the machines and munitions lies in soundly engineered well-trained organizations. It is a matter of organization—organization throughout, far-reaching and effective.

In more normal times, a discussion of the organization of large-scale engineering work would warrant, I think, initially defining the type and character of the particular engineering enterprise. In form and structure of organization and the procedures for its functioning, the controlling factor is the work to be done. Since the work to be done will vary greatly in different types of enterprises, the specific form and structure of the organizations would necessarily vary correspondingly. There are, however, many general functions common to all engineering enterprises. These include:

Determination of the basic requirements in accordance with the best known standards

Preparation of specifications for technical apparatus and equipment

Selection of the best route or location for the installation

Obtaining and processing of the raw materials

Employment and training of suitable construction crews

Laying out of proper schedules for delivery of all materials to make for the most efficient and expeditious construction

Preparation of proper operating procedures based on the engineering requirements

Arrangements for putting the project into service to obtain the maximum advantage of the new installation but with the minimum disruption to existing installations

Following up the completed installation to ensure that it functions in accordance with its intended engineering design and to correct any defects in design or construction which may develop under actual operation.

What are the underlying principles of organization, recognition of which has given this nation its power and its know how? Organization is designed to bring all available knowledge and all available energy to bear upon the specific problem at the time most needed. It presents first a problem in specialization, or division of labor, and then a problem in co-ordination of all the specialties and parts of the organization so that it will function as a single, unified, and cohesive team.

Long ago Adam Smith, pointing out the great economies which are the result of specialization of labor in the production of goods and services, wrote: "The greatest improvement in the productive powers of labor, and the greater part of the skill, dexterity, and judgment with which it is anywhere directed, or applied, seem to have been the effects of the division of labor." In principle his statement is as true today as when it was written a century and a half or so ago. In practice specialization has been carried to an extent undreamed of then. And the more you divide the work in order to specialize on the particular parts, the more you have to co-ordinate in order to bring all the parts together in a whole. As the degree of specialization increases to improve the productive power of labor, and the necessary co-ordination follows, obviously the greater the supervision necessary—in other words, the more the whole enterprise depends on sound and able organization. There has been so much discussion of the wonderful results of science that I think the public has lost sight of the fact that science by itself does not produce the goods and services that benefit the public—that until a competent organization takes the results of scientific research and translates them with precision and economy into products and services, the public gets little good from the research.

Industrial organization for large-scale production is particularly American. Relatively to other countries, we have advanced more in organization than in science. That is why making airplanes and tanks is down our alley, even though we had made fewer airplanes than others and no tanks. And the capacity for organization functions in the building of ships, guns, radars, and all the other engines and gadgets of war.

In large-scale enterprise, consideration of divisions of labor and functions should embrace:

Separation by broad categories, such as research engineering, manufacturing, and operations.

Specialization within each category, in order that the work assigned to each individual in each part of the organization may bring to bear, recognizing the limiting capacity of the individual, the maximum dexterity, efficiency, and knowledge in handling the assigned work.

Recognition of the distinction between the respective functions of line and staff work. The line work, which has to do with the actual on-the-job operations inherent in the work to be done, must be supported by staff work responsible for methods, procedures, and general direction of the work.

Decentralization of the work, taking into account geographical factors, to the end that the work will be performed where it can be handled most economically and effectively.

Recognition of the proper relationship of supervisory people to the total force. The importance of an adequately trained and numerically sufficient supervisory force, commonly referred to as "overhead," is worthy of emphasis. Overhead is essential, because without it the result would be an untrained, undisciplined, and undirected force. The exact relationship which will produce the most effective results is dependent upon the type and amount of work to be done, but even in the simplest operation some overhead is necessary. It is an established military fact, for example, that an adequately supervised army is more effective than many times its number of unorganized, untrained people. Hence, separate branches of the army are organized into squads, then grouped into platoons, and so on, until arriving finally at the collection of army corps constituting the entire army. Each unit is given suitable leadership—corporals, sergeants, lieutenants, on up to the commanding general. Any other organization must follow much the same pattern.

Flowing directly from the division of labor comes the second problem of organization namely, the co-ordination between all units. Co-ordination involves:

A common objective mutually understood and subscribed to by all in the organization.

Cohesive direction accomplished by having definite lines of responsibility spreading out from the executive head of the enterprise so that each individual in the organization knows what his definite responsibilities are and to whom to turn for decisions and assistance.

Understanding on the part of each unit of the functions and responsibilities of every other unit. Such mutual understanding is essential for smooth co-operative working.

A sympathetic understanding by the personnel as a whole of the ideals and traditions of the enterprise and of the general reasons for approved procedures.

The aim of co-ordination is that the organization as a whole shall function as a single team; no organization can be successful unless this result is effectively achieved. This co-ordination, to be fully effective, must represent all work done by the various branches and individuals of the organization, with each usually doing a clearly defined and component part of the whole, but all subordinating individual prominence to the efficiency of the whole. I am but quoting the definition of teamwork. It is an intangible quality of organization—one that cannot be shown on charts; nor can any very precise formula for attaining it be stated. Above all, it should embody a spirit of service, the significance of which lies in its instilling not only an appreciation of the importance of the individual's contribution—no matter how humble the assignment—to the success of the enterprise, but also a realization of the deeper meanings and values of the individual's way of life, to be achieved through his part in the skillful execution of soundly conceived and well-organized plans.

BELL SYSTEM ORGANIZATION

Many teams are working together in this country to meet the challenge for maximum production under the impact of war. The Bell System is one such team.

Since the Bell System companies are responsible for rendering a large part of the telephone service to the United States they necessarily constitute together a large and geographically extensive organization. There are about 400,000 employees, inclusive of about 10,000 engineers and scientists located throughout the continental United States. The nature of the enterprise embraces a very broad scope of activities related to electrical communication. These activities run all the way from the elements that enter into an electrical communication system, including raw materials and ideas, through the gamut of research, development and design of apparatus and equipment, manufacture, fundamental engineering plans for future development, design and construction of operating plant, technical problems of maintenance and operation, and studies of technical quality of service—the final product of the organization. An important requirement is to insure that no new device or equipment is introduced into general public usage until it has been subjected to such engineering and laboratory tests that any question as to its adaptability is resolved beyond a question of doubt. Thus it is never necessary to put into public usage untried and unproved devices, which, if not suitable, could have, because of the highly co-ordinated nature of the telephone plant, seriously adverse effects.

By broad categories the work is divided as follows:

Research and development are concentrated in one large organization (Bell Telephone Laboratories, Inc.) which carries out fundamental studies in the branches of science underlying the industry, studies new ideas that relate to telephone equipment and materials, and constantly develops new or improved apparatus and materials for use in realizing the objectives of the enterprise.

The Bell System source of supply (The Western Electric Company) is responsible for providing apparatus and materials as required, manufacturing them in accordance with Bell Laboratories specifications or arranging for their manufacture by others, making complete installations of telephone central offices or other equipment, repairing recovered apparatus, and salvaging useful materials from discontinued plant.

A centralized general staff is maintained by the American Telephone and Telegraph Company to carry out staff work of such a general nature that it is applicable to all the operating companies in various parts of the country and therefore can be done once for all. This staff work includes the investigation of new ideas, the study of service requirements, determination of field of application and programs for the introduction of new types of telephone equipment and materials, preparation of general technical information, including that required for the design, construction, maintenance, and operation of the plant.

There is a series of 19 autonomous operating companies, known as Associated Companies, each with its engineering and other operating departments, and each responsible for telephone operations in a particular part of the United States. In addition, the long lines department of the American Telephone and Telegraph Company provides long-distance service to tie together the long-distance facilities of the System. Individual operating companies are subdivided geographically into divisions and districts in accordance with their operating requirements. The engineering work is in part concentrated in the headquarters of the companies and in part distributed geographically by divisions and districts according to its nature.

Further specialization is attained within each of the broad categories:

Each company is departmentalized and the work divided within each department to meet its specialized

requirements. Highly functionalized staffs are necessary and provided for. This is particularly true within the engineering and research departments, which are organized and equipped to go deep into the heart of all communication techniques.

All of the work, whether line or staff, engineering, research, or operations, is under the direction of competent supervision of varying grades. On the average one out of each eight employees is a supervisory employee.

An unusually high degree of co-ordination is required. In handling even the simplest telephone call, for example, the procedures at the orginating and terminating points, as well as in all the intermediate links, must be carried out in co-ordinated precision. The Bell System has been described as a team of 400,000 persons; an organization where the 400,000 can play their positions, knowing all the plays and all the signals, and knowing that what this team does is absolutely vital, for over its wires go many of the signals for all the other teams that are getting things done. To explore the conditions and to depict at any length the practices that have brought about this co-ordination and teamwork would require more space than can be devoted to the subject here. Suffice it to say that the high degree of co-ordination of the organization reflects in a great measure the ideals and traditions with which the service is endowed and the common bond between people who know the real significance of working together to serve an outstanding common purpose.

The organization features described for the Bell System are but typical of those of many other large enterprises. And of course the Bell System is only one organization, collaborating with many others, to effect maximum production for the war effort, in which effort the engineering departments have a unique responsibility. Engineering, embracing as it does the origin, cultivation, and integration of powerful forces, has a major role in the full, complete, and far-reaching organization of America's productive forces for total war.

The military objective is not new. On the contrary, history records that engineers were first military men. In English history, for example, the word "engineering" was originally applied to "the operations of those who construct engines of war and execute works intended to serve military purposes." Now again, engineering must concentrate on military rather than civil objectives. The responsibility is grave, since the military outcome holds in its crucible the destiny of mankind. But with confidence born in the knowledge of the integrity, wisdom, and ableness of our organization leadership we may have faith that our capacity to produce will be organized with maximum effectiveness in this our most troubled hour. Looking beyond that, our work and spirit of today nourishes the aspiration of tomorrow—for a new world, unhampered by oppression and tyranny—a world in which the full power of organization will be utilized to produce a civilization dedicated to the well-being of mankind and bringing benefits to the individual which the boldest of men cannot now visualize.

The Engineering Organization of a Large Industrial Business

R. C. MUIR

The General Electric Company, with which I have been associated for 37 years, embraces more than 50 lines of products, which vary greatly as to type—for example, measurement instruments and steam turbines. The policy of the company, favored by the newness of the art, has been such that no product has been frozen for any great length of time, and there has been a constant flow of new or improved products to meet the ever-expanding uses of electricity.

With this background it is apparent that the engineering branch must be supported by a strong research organization, a strong sales and sales-engineering organization, and a versatile and able manufacturing organization.

Several forms of engineering organization could be designed to take care of an operation such as this; but before putting any one of them in a one-line diagram it might be well to set down a few principles which seem quite fundamental in the organization and management of the engineering activities of a large industrial organization. The problem is one of obtaining directness of action and at the same time freedom of action, without conflict.

UNDERLYING PRINCIPLES

We may view the form of organization as a mechanism or structure through which management functions; and, as with a well-designed machine, it must be simple if it is to be efficient and direct in action. It should clear the path of obstacles, allowing to the individual engineer freedom to do, rather than specifying what he cannot do.

We are in a business; and the engineering organization, being a part of that business, cannot be considered by itself; it must be designed into the fabric of the whole organization. Engineering should be tied into almost every phase of the management of the business, from the top engineering executive to the engineer in charge of any one line of products.

The form of organization at its best should be subordinate to personnel. The organization should be shaped to meet the particular qualifications of the men, rather than the men to meet a specific or exact form of organization. This is the principal difference between industrial and military organizations. E. W. Rice, Jr., former AIEE president, once said that the most perfect form of organization in the world would fail unless it was supported by an adequate personnel, but that a very good job could be done with the right people even though the form of organization was quite inefficient.

The central staff should be small and compact, and in so far as possible it should confine itself to the broad direction of the work. The individual engineers who head the various departments should be built up by placing upon them complete responsibility for the engineering of the line of products to which they are assigned. Responsibility should always carry authority. No one in the engineering organization should be more than one or two men removed from the central head of the organization, whose door should always be open to any engineering employee.

The service of consultants, experts, and freelances should be available to those carrying the responsibility for the product, but these specialists should not be in authority. It is preferable to locate them in the laboratory or laboratories, where they can serve the entire engineering organization, rather than to duplicate these talents and facilities in each engineering department that is responsible for a specific product.

The over-all engineering department should be supported generously by engineering committees on materials, practices, applications, or technical problems common to a number of the product engineering departments. Engineering conferences are helpful.

It is most satisfactory if you can develop your own men, choose a wide variety of talents from a wide variety of schools, plan the development of your men 15 years or more ahead, keep the age line healthy—that is, always have new talent coming along and plenty of reserve. Always have a runner-up for every important position so that embarrassment cannot result from the loss of any one man. Constant vigilance should be exercised to see that no one is kept too long in a position that does not tax his ability. Educational courses are tremendously important. Loyalty, spirit, and morale cannot be legislated; these qualities must be cultivated and developed, and above all, exemplified.

ORGANIZATIONAL PATTERN

In regard to the form of organization itself, there should be an engineer executive in charge of design or product engineering. His staff should include members who concern themselves with operations, budget making, expense control, and other administrative matters; members who know the products and who concern themselves with quality control, the research and development program, and the personnel and the personnel requirements; and members who obtain and train the personnel for all the departments. It is preferable to have a number of the staff members broadly trained so that they know something of the business, the development program, and the personnel. These staff members can carry on with less dependence upon the executive in charge and at the same time be making larger jobs for themselves.

The commercial-engineering organization and the research organization could also report to this engineer executive, but in an organization as large as the one under consideration it has been found desirable to have an engineer executive in charge of the commercial-engineering organization (which includes the field organization) and another executive engineer or scientist in charge of research. These latter two report directly to the president of the company but are closely co-ordinated with the design-engineering organization.

The executive in charge of engineering is a member of the president's advisory committee or the committee on general operations; thus providing at the top a connection for engineering with the business and policy points of view. He, his staff, the Research Laboratory, the commercial-engineering department, and consultants are functional, operating, as it were, across the entire organization.

The executive in charge of engineering who has a good staff has little occasion to worry about day-to-day operations, because the organization carries these out very well. He should keep well informed, however, on the operations in all departments. This he can do through short quarterly reports backed by frequent contacts with his staff members. Only in this way can he give broad supervision to the work and make wise decisions in those matters which come to his attention every day. This familiarity also permits him to show an interest in the work of any department, which has a marked influence in improving spirit and morale.

If the specification of a strong central engineering staff is met, the executive in charge and his staff are looked to as one by most of the organization. The staff carries the management load, largely, leaving the executive in charge sufficient time for the consideration of major projects, changes, or matters which only the executive can handle.

Since the products vary greatly, it would seem that each product might support its own design-engineering organization. In some of the more comprehensive lines, such as motors, transformers, switchgear, or turbines, where types or sizes make natural division points, two or more engineering departments are preferable to one.

Each design-engineering department is headed by an engineer who functions in management through a committee of three —one representing manufacturing, one representing sales, and one representing engineering. These three are responsible for the business in that line, under the broad supervision of executives higher up. The engineer also has representation on the product committee, which plans the product for the future, and on those co-ordinating committees which have to do with such general problems as heat transfer, lubrication and bearings, insulation, and so on, that are of interest to him. He is responsible for the design, development, and production engineering, and must have an organization commensurate with the job.

Each of the more than 50 engineering departments varies somewhat in the form of organization, because of variations in product and in the men who make up the department. The engineer does not attempt to carry on his payroll highly specialized men whose full-time service he does not require; these are carried by the laboratories or the central staff. On all technical matters he reports directly to the engineer executive in charge (or his central staff), but this is not practical in the case of administrative and production matters in a wide-flung organization that has many plants in different parts of the country.

Policies covering manufacturing and engineering personnel housed under the same roof must be harmonized; and this duty, and the operation of the plant at large, is performed by a works or plant manager, who also carries the intermediate responsibility for engineering operations in his plant. The latter is a full-time job for a high-grade man, so the plant manager is supported by an assistant who assumes this responsibility.

Each plant also should have a laboratory for material testing, process control, and such other work as may be carried on better by a laboratory than by a manufacturing or engineering department. Specialized laboratories, such as those dealing with plastics, high voltage, should be maintained by those departments that can justify them. A research laboratory should serve the entire group of laboratories and engineering departments.

The functioning of the engineering organization, then, is directly from the office of the executive in charge of engineering to the various engineering-department heads on technical matters, and through the works manager to the various engineering-department heads on administration and production matters.

Except in very special cases, the executive in charge of engineering is not brought into the matter of engineering of orders for production. This is handled directly by the individual engineering-department head. He co-operates with the factory in planning the manufacture and scheduling production, and follows his designs through the factory until the completion of manufacture and test. He is responsible for the suitability of the product and has the authority to pass it, or to hold it until he is satisfied that it meets the requirements. It is his responsibility to obtain such outside assistance from consultants or laboratories as he may require. The executive in charge of engineering always has the opportunity to review the designs or engineering on any specific order and to hold engineering conferences on such orders when they are sufficiently new or outstanding to warrant it, or when they depart radically from former practices.

Therefore production engineering of any product is direct, and there is no pyramiding of approvals or responsibilities. But there must be a constant check from the head office and from the works manager on the meeting of schedules and on the quality and the cost of the product.

Each engineering department carries on a very active development program in which the engineer is guided through his product committee and the commercial-engineering group. A budget of projects to be taken up, with periodical reports as to progress, is always valuable; and frequent check on them by the central office is helpful and stimulating. It is in development work that engineering conferences and co-ordinating engineering committees are particularly valuable. We find that even though business in a particular line of products is extensive and the engineering department is capable and well supported by its own testing and developmental facilities, talent from outside that department is helpful.

A reasonable proportion of the personnel of each engineering department should be men primarily interested in the development or research, as it is only with those who have such abilities that development work can be carried out successfully. The inherent ingenuity and the natural unrest of persons of this type assure a forward-looking development program.

However, in addition to the development work carried on in the established departments, the General Electric Company finds it well to encourage research and development in its Research Laboratory and other laboratories, as well as by consultants and freelances, quite independently of any specific objectives set up by the design-engineering departments.

It has been the policy of the company to recruit technical students from graduating classes and to train them for the various positions in the engineering department, the commercial department, and the manufacturing department. Inbreeding is automatically avoided by the practice of recruiting from a wide number of schools, by deliberately choosing different types of talent, and by means of a test training course which requires the student engineer to obtain experience in several testing departments or laboratories before he is assigned to a specific engineering department. About 10 to 15 per cent of the newly graduated engineers entering the service of the company have the opportunity of participating in a three-year course in advanced engineering, during which period they have assignments in several different departments.

These provisions, in addition to a generous policy of participation in sponsor and trade-society activities, and the numerous customer contacts made in the normal course of business, all tend to prevent narrowness and to train men who know the organization and know how to work collectively in it. They also develop in the men a spirit of loyalty and co-operation that goes a long way toward making management's job easier.

The development of personnel comes closer to the central office than any other operating function, and this is as it should be. For this reason, it is well for the executive engineering head and all the other members of his staff, aside from those who give their entire time to engineering personnel, to be thoroughly interested in and collectively acquainted with those in the various engineering departments. In this way not only can the various departments be manned with adequate talent, but the men can be moved around and given broad development for positions more important than those for which they would otherwise be qualified.

There may be many variations in the organization setup or in the method of functioning just described, but the principles underlying the form of organization and its functioning remain substantially unchanged. As a matter of fact, as the business of the General Electric Company has expanded both as to variety and volume

of products, we have found it advisable to make modifications in our form of organization from time to time. Such changes have seemed desirable from the business point of view rather than from the engineering viewpoint.

At present there are four main departments of the company. The largest, which covers apparatus lines in general, is in itself organized and operated very much as described above, the engineer in charge being an executive officer of the company. The managers of the other departments are executive officers of the company. These departments do not have an executive officer in charge of engineering, but this may come about should they grow in size or complexity.

The president of the company has on his staff an executive officer of the company who has the responsibility of co-ordinating and supervising broadly the engineering of all of the departments of the company. He also is responsible for the co-ordination of research and engineering. Hence, the over-all operation or effect is as described.

I should like to suggest a concept of an ideal engineering organization in operation. Imagine the form of organization to be an edifice or workshop, a structure of offices or functions where men do useful things; a structure stable as to framework but flexible as to partitions. Then picture the living or mobile part of the organization, a continuing, never-ending flow of men through this structure, who work as they go and progress according to their contributions. Each year an army of new men who have diverse possibilities enter the structure, opportunity awaiting them, ambition and ability advancing them. As these new men enter, older men, who started some 40 years earlier, leave the structure—make their exit from those final offices to which their contributions have carried them.

All through the structure there is a moving up or rearrangement of men, often accompanied by the moving of a strut or a partition to give the new incumbent more freedom. Sometimes new partitions or rooms are added to take care of expansions or new work. The decisions as to which men shall move and to which offices they shall move are made by the men at the top of the structure, assisted by the men in the various pinnacles, all of whom have been encouraging, guiding, and directing the men who are now ready to move up to higher positions.

The men in these top positions also will move on when their time comes; and one measure of their success is how wisely they have chosen and how well they have trained those who are to succeed them.

The output or contribution of the collective group is governed by many factors—the ability of the men, their supervision or direction, the structure in which they work. These factors might be likened to the carbohydrates, proteins, and fats in our diet. Fully as essential, however, are those intangible factors—loyalty, morale, co-operative spirit, pride of heritage, an intense desire to serve mankind well—which might be likened to the hidden vitamins in our food, without which we languish and fall the victims of disease. These intangible factors are developed by the opportunities and the traditions of the engineering profession and of the company of which the engineers are a part.

Engineering as an Implement of Management

H. B. GEAR

From the dawn of recorded history, the engineer has designed structures and devised procedures for their erection; for the glory of a king, as in building the pyramids; for the welfare of a people, as in the construction of great stone aqueducts; in creative steam engines that eased the drudgery and speeded the output of workmen; and in recent generations in developing the marvelous uses of electricity in applications to light and power, to communication, and to radiobroadcasting.

The aqueduct was no doubt the result of the application of the discovery of the use of stones in the form of an arch. This detail of construction, impelled by an aggressive Roman civilization, became the basis of great public works beneficial to many.

The story of Watt and the tea kettle may be ficticious but it illustrates again how a principle first observed in a very small way can become, at the hands of an engineer, a mighty force in the advancement of civilization.

The discovery of the relations between the electric current and magnetic force remained for some years only a laboratory experiment. In the hands of engineers it became the foundation of electricity supply systems. Such inventors as Brush, Thomson, Edison, and others made electric lighting and power applications practical for general use. In later decades these advantages became available to all classes of people.

In like manner, the early telephone of Bell was looked upon as an interesting toy. It was exhibited first at the 1876 Centennial Exposition. The value of the telephone was not fully realized until about two decades had elapsed. As a young man when I came to work for a utility company in Chicago, and had an engineering degree from Cornell University, I had never talked over a telephone. There were none on the campus at Cornell University, and none in the town I came from in Ohio excepting between the fire station and the downtown stores. The telephone did not become an instrument of the people until 1896 and 1897; when the ten-party line was introduced and the telephone was made available at $1.50 a month. But Edison and Bell saw a future for their inventions and because of the breadth of their vision and the courage of their convictions, they brought the world to their feet in admiration and respect.

The work of early radio engineers was catapulted to the state of an industry by the forces of a world war. There the vacuum tube made possible communication between different arms of the military and naval forces, in ways previously unknown and of untold value. The developments of the war period led to the introduction of public broadcasting and the foundation of a new industry. This industry, to an even greater extent than the light and power and the telephone industries, was brought to an early state of maturity by a host of competent engineers whose contributions are too many to be enumerated here.

In the 1890's it was often said that electricity was in its infancy, and looking back upon the growth its use has made in 50 years, the truth of that statement is readily apparent. In those days generators were called dynamos and they were driven by steam engines through shafting and flapping belts. The common sizes were rated at 50 to 100 kw. Lighting of stores, factories, and outdoor spaces was done by arc lamps supplied from series circuits. Each circuit was supplied by its own dynamo and each lamp absorbed 50 volts at ten amperes. Dynamos were designed to carry 100 lamps at 5,000 volts, but one company made 150-light machines at 7,500 volts.

In larger cities arc lighting stations were readily distinguished by the large number of overhead wires leaving the station. Incandescent lighting was served from Edison three-wire d-c systems at 115/230 volts in the central parts of large cities, and from a-c systems in outlying parts.

In Chicago the outlying sections were separate municipalities. After six of these suburban municipalities had been annexed in 1890, there were some ten electric companies supplying service in the city. Six of them were giving incandescent service and four were selling only arc lighting. Four companies sold incandescent service from a-c circuits and two from d-c Edison systems. Of the four companies selling a-c service there were no two that used the same system. Three companies used 1,100 volts and one had 2,200-volt single-phase circuits. Frequencies were 60, 125, and 133 cycles per second. Two of the companies had two-phase generators supplying single-phase lighting circuits and a few two-phase elevators in hotels. Power service was given by two companies serving industrial areas from 550 volt d-c circuits. Secondary voltages were 55 or 110. Where 55 volts was used it was necessary to place a separate transformer for each building. This required from four to five times as much distribution-transformer capacity as is needed in modern systems.

Early in the 1890's it became apparent to manufacturers and to utility operators that the results of the active competition that had existed in the previous decade had been of doubtful benefit to the user of service, the manufacturer, or the utility investor.

Duplication of plant and multiplicity of systems had nullified the possibility of attaining the benefits which later were found to accrue to producer and user alike as the sale of electricity became more general. By sheer necessity there ensued a period of consolidation out of which there came the adoption of standards of frequency, voltage, and systems of distribution.

At the convention of the National Electric Light Association held in Chicago in 1898, the program was devoted to papers

and discussions dealing with technical and operating problems. The comparative economy of different methods, the use of a demand system of charging instead of a simple rate per kilowatt-hour, and the merits of d-c versus a-c systems of distribution in large cities were discussed. Matters of sales policy, management, personnel, or finance were considered matters to be discussed only in private with acquaintances in other companies. These matters were of minor importance as compared with the operating troubles that had kept engineering practices in a continuous state of flux.

When some degree of standardization became possible, at the turn of the 20th century, several of the larger utilities adopted for city distribution the four-wire three-phase system operating at 2,300/4,000 volts. With this settled, it remained to replace the inefficient tangle of competing systems that existed in certain parts of Chicago with a type of distribution capable of development as the load required, and with more efficient generating stations. The job involved removal of old equipment operating at odd frequencies, and at voltages too low for the distances to be covered. Distribution transformers were replaced by newer designs of much better efficiency and more dependable insulation. The economics of secondary distribution were determined and proper sizes and transformer spacings selected.

Single-phase 2,300-volt feeders were arranged in such manner that when a demand for power was developed two additional wires could be added to give three-phase supply.

Thus a flexible system with well-regulated voltage was made ready for the rapid expansion of use that was to follow. To the young man who was thrust into that confusion of systems and was privileged to bring order out of chaos, it seemed inherent in the nature of a light and power system that it should present interesting problems for the special benefit of young engineers. A decade later it began to dawn upon him that an electric system was created as a business enterprise, not merely to provide interesting problems for young engineers. He was to learn in subsequent years that he and his associates in the work had in fact been using their engineering as the implement of a management confronted with many harassing problems of operation.

When engineering practices became more standardized, types of construction used became more nearly uniform, and the work of extending and operating the plant became more nearly routine, then operating troubles were less frequent and reliability of service increased. The result was a steadily declining trend of cost of supply and of rates of charge which in turn brought greater public acceptance of electric service and many new applications of its use.

The energies of management were thus freed for development of the enterprise, for increasing the efficiency of production and distribution, and for extending electric service into new fields of usefulness. These benefits to management accrued as well to investors who in early years had risked their funds in a new and hazardous enterprise, had seen their investment rapidly depreciated by obsolescence and their dividends withheld by the necessity of using earnings for making plant extensions which could not be otherwise financed. The final result was that the use of electricity in the home passed from the status of a luxury enjoyed by the well-to-do to that of a vital necessity enjoyed by millions of residents of cities, villages, and farms.

This bit of history is one example of achievement that had its foundation in engineering and invention. The cathedrals of other centuries have a counterpart in the massive power houses of our century. Indeed their high-vaulted turbine rooms have suggested to some the designation "cathedrals of power."

The story of the development of electricity supply has its parallels in the growth of transportation, communication, and manufacturing. In each of these fields the engineer has been the implement of growth and the reinforcement of the energies of the leadership in their onward march.

In these days of expanding activities, the picture of engineering achievement is better suggested by the image of many structures making up a great city, than by that of a cathedral. There are many buildings of many kinds, each useful in its own way. The young engineer, and sometimes the engineer who is not so young, needs at intervals to leave the particular place of his daily work to see and talk with others. Occasionally he needs to take time out to rise above the scene where he may see the whole city and be aware of his place in it.

The value of engineering as an implement of management is summed up in three elements:

(a) Knowledge of intricate details coupled with the intelligence to apply them to the solution of engineering problems that present themselves

(b) Ability to co-ordinate his own specialized knowledge and experience with the knowledge of those working in other fields, thus bringing every available resource to bear on the problem at hand

(c) Ability to co-operate with the whole team in bringing projects to a successful completion.

When engineering is thus used as the effective implement of management, it becomes likewise the implement of human achievement.

Discussion

Opening discussion on the three addresses President Prince suggested that "engineering is making a fundamental change in all our ideas of government and social structure generally. The weight of that may perhaps be brought home to you when you realize that the 12 good men and true who constitute a jury are the court of last resort in the determination of a fact. You can see they might have been able to do a job at the time the Government was setting up a program. At the present time, if you pick up 12 good men and true from the street corner and ask them to pass on any such subject as the regulation required in a transmission line, or any one of the many technical subjects with which you are familiar, you will see that we have outgrown the whole structure.

"In a sense, our various industrial organizations are experimental laboratories in which we are trying to find out some method of handling our society so it can operate in the world we have built up. If we can find some way to handle all of these forces that we have learned to handle in a technical way, or association way, which means organization, then we will have made it possible to go into a new world on a small scale. Of course experiments are being made by all of the organizations in the United States, experimental approaches to just that sort of problem."

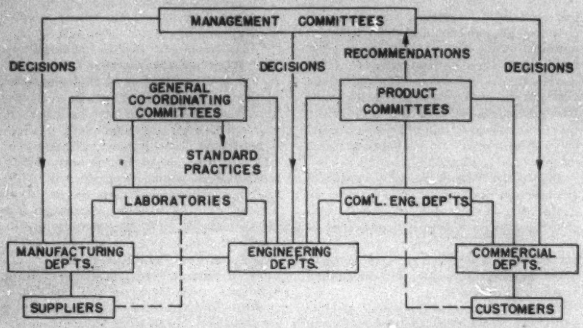
W. F. Simms, Commonwealth Edison Company, commenting on Mr. Gear's talk, pointed out that "in the earlier days of utility systems the head of the engineering department was comparable to a company commander in the Army operating under conditions where the field of operations was very largely under his direct observation, whereas today he is in the position of a general commanding a much larger body of troops on a very much more extended battle front and his information must come from the unit commanders in the field. The engineering department head is, also, very largely dependent for his information upon the reports of his assistants in charge of the various phases of the work. Under these conditions, administration and co-ordination of effort become a very much more important part of his work and the working out of engineering details becomes more and more the responsibility of his various assistants. This leads to the conclusion that those of us who are engaged in the direction of the engineering work of large utility organizations could very well reverse the title of Mr. Gear's talk and give consideration to 'management as an implement of engineering.'"

GENERAL-ELECTRIC ORGANIZATION CHART

P. L. Alger, General Electric Company, Schenectady, N. Y., presenting the accompanying diagram of General Electric organization, said, in part, "Electric power is unique in the diversity of its application, and also in the interconnections it creates between widely separated devices. The electrical industry, therefore, deals with controls, or nerve systems, if you please, that tie together a great variety of machines, both mechanical and electric, causing them to function as elements of a single system.

"Thus, the various departments of an electrical manufacturer cannot be set up independently, with only executive relationships, as is done in many other industries. The engineering of each separate department must be closely co-ordinated with that of other departments.

"The diagram of General Electric's organization is by no means exact, nor is it permanent. On the contrary, it is an idealized picture of an ever-changing situation. It may best be understood by an analogy with the familiar form of our national government, with its distinct executive, legislative, and judicial functions. Montesquieu, in his 'Spirit of Laws' wrote



Technical organization of the General Electric Company

in 1750 that the separation of these three functions is essential to freedom, as borne out by the long history of England. The Founding Fathers accepted this principle as basic, and designed our constitution around it. I am profoundly convinced that this principle is sound, and that no large organization of human beings can long endure unless the executive, legislative, and judicial powers are well organized and are thoroughly independent of each other. In this diagram of the General Electric technical organization, the principle is adhered to by providing:

"1. An executive head of each department, who is solely responsible for all decisions made and results obtained in his sphere of action. The respective heads of the commercial, engineering, and manufacturing departments for any one product form a management committee of three, this management committee having over-all responsibility.

"2. A product committee, or, if you please, a legislature, for each line of apparatus, including representatives of engineering, commercial, and commercial engineering departments. The commercial engineering function is essentially that of planning for improvements in the product, and especially for adapting the product to fit better into the complete electromechanical system of which it is a part. Usually the commercial engineering representative is chairman of the product committee. The product committee writes specifications, sponsors development programs, and proposes new undertakings. Its conclusions are submitted to the several management committees concerned, in the form of recommendations only, which the management committees may accept, defer, or reject, as they see fit. The Product Committee has no executive function whatever, and cannot override a Management Committee veto.

"3. A general co-ordinating Committee for each material, process, design feature, or other important subject, that is of importance to several different departments. The members of these committees are scientists, experts, and specialists of all sorts, who know the last word on any technical question. The co-ordinating committees, therefore, form the courts of highest authority on all technical matters. They exercise the judicial functions of interpreting the laws of nature, and saying what can and what cannot be done without incurring nature's unfailing punishment of transgressors of natural laws. The co-ordinating committees have no power whatever to enforce their decrees, however. The executive head of any department can go right ahead contrary to their dicta, if he so desires. If he is right, the committee will become better educated, or will be revised. If the committee is right, the executive officers of the company may take corrective action against the erring department head.

"The membership of the product and co-ordinating committees is not clearly defined, but is continually changing, in accord with the principles of flexibility and flow of personnel Mr. Muir has expressed. Most of them grow up naturally to fill a need, and only gain formal recognition after they have proven their value by results attained.

"There are two outstanding advantages of this form of organization: In the first place, it encourages creative developmental work or research by individual departments where the experts concerned deal directly with the factory and practical men. This is possible because such experts have contacts with other departments, which keep them stimulated and provide them with suggestions. Also, they can render reciprocal services to other departments, enhancing their opportunities and rewards far beyond what they could expect if confined to a single department. The ideal sought is for every engineer to do some research, and for every scientist to be in some degree an engineer.

"In the second place, this plan permits unlimited extension to additional departments, or associated companies. By separate organization of the research and developmental activities, the planning activities, and the business responsibilities, it becomes possible to plan co-operative research and make plans quite independently of economic conditions. As time goes on, we must expect greater government participation in planning, and a greater sharing of the fruits of research with all who may make use of them. Thus, this plan of organization may prove useful in the development of that after-the-war era of co-operation to which we are all looking forward."

GETTING IDEAS FROM RANK-AND-FILE EMPLOYEES

In response to a question from President Prince on methods of getting ideas up through, as well as down through, an organization, Mr. Sullivan said that in the Bell System this was done "by frequent meetings with the employees and by first giving them as much information as possible on all the reasons for all procedures." "We want our people to be reasonable in their dealings with each other and with the public," he said, "and in order to be reasonable, they must know the reasons." He mentioned that in some of the System's companies progress is being made along lines advocated by War Production Board Director Donald Nelson and others to get the advantage of group meetings on particular problems. "That requires extensive conferences at all levels of supervision," he said.

VERTICAL VERSUS HORIZONTAL ORGANIZATIONS

In a discussion on the relative merits of vertical and horizontal types of organization in engineering operations, Mr. Muir expressed the belief that the form of organization is less important than the abilities of the personnel, the freedom they are given, and the co-ordination existing between departments. Mr. Gear cited the experience of Commonwealth Edison Company to show that a form of organization which was effective at one time might be outmoded by developments in the company or the industry, and a change in the alignment of functions might be necessary to meet existing conditions.

APPLICATIONS TO SMALL INDUSTRIES

A request from the chair for questions from the point of view of the small company produced two queries, one on operation as distinct from production, and one on personnel. The question, "just how would management go about to produce an operating engineering department?" was answered both by Mr. Sullivan and Mr. Muir. The former explained that in the telephone industry, "operations" are considered as comprising plant maintenance, commercial operations, and actual handling of equipment, or traffic. Co-ordination of these with the engineering department by having the heads of departments in close touch assures that operations are carried out in accordance with engineering design, he said. Mr. Muir stated that in the General Electric Company, responsibility for plant operation—continuity of service, supply of electricity, and so on—is centralized with the plant engineer, with the plant manager at hand only to approve the plant engineer's recommendations or specifications for appropriate action. In designing new equipment, the plant engineer has the assistance of the construction engineering department. The operation of the plant is thus organized in much the same way as is a design engineering department, he said.

On the subject of personnel, another questioner commented that in the United States people are prone to think "the organization is made for man and not man for the organization," and that while in a small company there is no question but that the organization must be fitted to the man, he had been interested in Mr. Muir's policy of doing the same for a large organization, and wondered how far this could go. Mr. Muir declared that, in agreement with similar statements from Mr. Sullivan, he considered personnel fundamental. "You cannot do anything without men," he said.

"The way to develop men is to give them freedom, latitude; not tie them down; not give a man only one job, or hold him in any job that does not continue to tax his ability. Otherwise, we don't have progress. As I have said before, if we don't have progress, or develop men, we have no longer an engineering profession; we have a craft.

"Since we are developing our own people, we never consider an engineer as a job but as a man. The particular job is whatever he makes it. We don't tie him down. It is quite probable that the head of a large department will not have the same qualifications as the man preceding him; he may be a better designer, or a better administrator, or executive: in which case he shifts the form of the organization. If he is a highly technical man, we support him by a highly capable executive or administrator; if he is a highly capable executive or administrator, we support him by a highly technical man. The job is constantly shifting, so as to give the incumbent all the freedom and latitude possible.

It works very well with us. But just as under a democratic form of government, it is much harder for the citizen than it is in a dictatorship, where he is told exactly what to do, it is much more difficult in our form of organization for a man who is brought in to understand that flexibility than for one who is trained in our departments. The new man has to learn that nothing is personal; everything is for the company's interest."

INDUSTRY VERSUS POSTGRADUATE STUDENTS

Dean A. H. Lovell of the University of Michigan posed a question with reference to the matter of postgraduate college students. Although praising the relations of industry with undergraduate training, he complained of the tendency of industry to allow to many no extra credit or standing for postgraduate work, and asked point-blank whether industry had any intention of broadening this general attitude which he decried.

Mr. Muir challenged Dean Lovell's statement with reference to industrial research, pointing out that industry has definitely recognized the position and contribution of the postgraduate student in the field of research. With reference to engineering, Mr. Muir said: "A man can learn only by doing," and pointed out that so far industry had been "unable to arrange with the schools any advance engineering work that is of any special value to the industry so far as concerns engineering."

DEFINITION OF AN EXECUTIVE

Concluding the discussion, Doctor H. S. Osborne, newly elected AIEE president, quoted a definition of an executive as "a man who makes decisions without having the facts." He went on to say that "in making a decision, of course, anyone desires to have all the facts that are available, and if the organization is a proper one, the facts can be reasonably collected and arranged and analyzed for the purposes of a decision. If when we have enough facts, they are allowed to speak for themselves—as they are if the organization is correct—such a decision should not have to go to the top executive. One of the fundamental characteristics of a good organization is that such decisions do not reach the top executives—at least not in the form of questions. But many questions come up on which it is not possible to get enough facts to let them speak for themselves. Those are the questions that should go to the top executive, and those are the questions that executives like."

Conferences at Summer Convention Relate to War Conditions

Six conferences, on widely varying subjects but all connected in some way with the war effort, were included in the program of the AIEE summer convention, held at Chicago, Ill., June 22–26, 1942. The conference on lighting aids to wartime production is reported elsewhere in these pages. The other conferences dealt with local engineering councils, particularly in relation to war activities and postwar planning; with educational matters under war conditions; with power supply for the war program; with electronic control of resistance welding, and with measurements of surface finish, both the latter being related to processes significant in war production. Brief reports high lighting the proceedings of these four conferences follow.

LOCAL ENGINEERING COUNCILS

Following up the conferences held at the South West District meeting, St. Louis, Mo., October 8–10, 1941, (*EE, Nov. '41, p. 548–9*) and at the AIEE winter convention, New York, N. Y., January 26–30, 1942 (*EE, Mar. '42, p. 148–52*), a conference on local engineering councils and their participation in civic affairs, with emphasis on wartime activities and postwar plans, was held at Chicago, June 22, 1942, with T. G. LeClair presiding. Speakers were Frank F. Fowle, head of Frank F. Fowle and Company, Chicago, who described the formation, objectives, and recent work of the Illinois Engineering Council; K. B. McEachron, General Electric Company, Pittsfield, Mass., whose topic was "The Coordination of Various Groups of Engineers in Massachusetts During the Preparation of a Licensing Law;" and K. R. Brown, consulting engineer, Des Moines, Iowa, who discussed the methods of co-ordinating the work of the engineering societies in that state. Active discussion followed, in which P. L. Alger, General Electric Company, and others participated.

EDUCATIONAL MATTERS UNDER WAR CONDITIONS

At the conference on educational matters under war conditions held Thursday afternoon, June 25, 1942, under the chairmanship of R. W. Warner, with an attendance of about 30, Professor Warner reread the 1942 winter convention resolution of the committee on education, concerning the matter of adequate continuation of technical education even under war conditions, as a necessary means of producing the engineers required for war effort as well as the engineers required for the after-war period.

Professor Paul C. Cromwell, New York University, presented a report concerning student guidance activities in the various AIEE Sections. This precipitated a long and general discussion of various aspects of the subject of vocational guidance for high-school students. Professor W. M. Young of Ohio University expressed the opinion that in his experience the quality of the home community has much more bearing on the quality of college students received from different high schools, than has the high-school faculty itself. He urged against trying to "wish on to high-school teachers" the job of professional guidance, pointing out that teachers are professional educators. He suggested that local Sections of the Institute and other engineering organizations should be the agencies through which local guidance should be promoted and handled in each locality, with the necessary co-operation of the high-school authorities. R. C. Muir of the General Electric Company challenged Professor Young's opinion, stating his belief that proper guidance of high-school pupils is only an integral part of the properly constituted high-school educational process which should be aimed toward the objective of turning out young people educated for life, rather than young people crammed full of academic knowledge. Mr. Muir defined education as the development of each individual to the limit of his individual ability, and in the direction of his interest.

Extensive discussion also ensued concerning the matter of vocational training, technical high schools, and related variations of these topics. Mr. Muir, P. L. Alger, and other noneducators present pointed out that too many high schools direct their curricula almost entirely toward college-entrance requirements, thus failing properly to orient the very large proportion of high-school students who do not or cannot go on to college. A better orientation of high-school courses toward the needs of average life conditions, supplemented by appropriate use of technical high schools and vocational high schools seem to be considered to represent the desirable trend in high-school educational effort. The New York State situation and experience was described by Mr. Muir; the Schenectady situation in particular also was touched upon by Mr. Muir and Mr. Alger. Mr. Alger called particular attention to C. E. Crofoot's paper on the

Mont Pleasant Technical High School in Schenectady (presented at the North Eastern District meeting, Schenectady, N. Y., April 29–May 1, and scheduled for publication in a future issue of *Electrical Engineering*), and urged all present to give serious consideration to such a high-school procedure in other communities. Some college professors voiced an objection to high schools encroaching upon the range of college technical subjects, but others recognized the necessity for high schools to do a better job of training for life rather than serving just as college preparatory schools. Mr. Alger defined vocational training as a procedure intended to interest boys in *doing* things, not necessarily a training directed toward any specific job or enterprise.

One speaker dwelt at length on the theme that high schools (and many others, including some colleges) have their curricula and procedures arranged to serve the "average student" thus "leaving the student of superior ability as literally the forgotten person." It was the general consensus that efforts should be made so to arrange high-school curricula and procedures as to prevent students of superior ability being hampered in their mental development by being held down to routine schedule; arrangements should be made whereby they can reach ahead and elect advanced work up to the limit of their ability.

POWER SUPPLY FOR WAR NEEDS

The combined session and conference on power generation, held Monday afternoon, June 22, 1942, with W. L. Cisler presiding, included one technical paper, scheduled for publication in the *Transactions*, a conference paper, and two special addresses. The conference paper on "Power Facilities and Problems in South America," by R. P. Crippen is tentatively scheduled for publication in an early issue of *Electrical Engineering*. "Power Supply for the War Program" was the subject of addresses by J. E. Moore and Edward Falck of the War Production Board; arrangements are in progress to secure clearance of these addresses also for future publication in *Electrical Engineering*.

ELECTRONIC CONTROL OF RESISTANCE WELDING

The conference on electronic control of resistance welding was held Wednesday morning, June 24, 1942, with S. B. Ingram, chairman of the joint subcommittee on electronics, presiding. G. W. Garman and E. H. Vedder opened the conference by briefly outlining the two principles, on one or the other of which all present systems of electronic control are based: the a-c control method and the energy storage method. They pointed out the most important features and limitations of these two methods, as well as some of the new trends in their development.

General discussion followed on several subjects, the first of which was the desirability of a simple, practical, nondestructive test for the checking of resistance spot-welds of aluminum.

Another subject which aroused active discussion was the need for educating in electronic practice the electricians who had the responsibility of maintaining and servicing electronic-control equipment. This is still a major problem in expanding the field of electronic devices. It was brought out that intelligent and complete servicing of electronic-control equipment necessitated the use and understanding of the cathode-ray oscillograph, which therefore, must be an early and important part of any such educational program.

The discussion also developed the fact that electrical engineers probably had much to learn as regards some aspects of resistance-welding technique, particularly relationships between thermal and electrical factors.

The following took part in the discussion: H. O. Klinke, B. L. Wise, P. W. La Hue, F. G. de Roza, B. B. Gravitt, Walther Richter, W. G. Dow, D. E. Marshall, H. A. Jones, R. E. Young, W. C. White, S. M. Humphrey, C. E. Mathies, H. C. Steiner. About 50 attended the conference. Of these, 18 were affiliated with manufacturers of electronic-control equipment, 7 with welder manufacturers; 9 with users of welding equipment; 7 with educational institutions, and 6 with public utilities. Several consulting engineers were present, as well as representatives of publications.

MEASUREMENT OF SURFACE FINISH

A combined technical session and conference on instruments and measurements, at which F. B. Silsbee presided, included, in the technical session, the three papers listed in the program, which ultimately will be published in the *Transactions*. The latter part of the meeting was given over to a conference on methods for the measurement and specification of surface finish. About 75 persons were present.

The first conference speaker, W. Mikelson, General Electric Company, emphasized the importance of accurate designation and inspection of machined surfaces in helping speed wartime production. "The performance of a machined surface depends upon the dimensional characteristics of its surface irregularities," Mr. Mikelson said. He named as most important of these characteristics, which vary with different materials and methods of finishing: surface roughness, surface waviness, directional irregularities in the surface plane, direction of irregularities above or below the nominal plane, pattern of both types of irregularities, surface profile, and contact area with mating parts. Surface roughness is defined by Proposed American Standard *B46* as the rms height of surface irregularities the peaks of which are less than 1/32 inch apart; surface waviness as the height of deviations of which the peaks are more than 1/32 inch apart. The speaker pointed out that interesting results have been obtained by a few experiments on the effects of finish on performance, although much more research needs to be done. Until practical instruments for measuring surface characteristics are available, a simple method of specifying surfaces in design and production is needed. The General Electric method, which has been used for ten years, uses sample gauge specimens to designate finishes. The symbols describing the specimens designate a specific value of surface roughness. The specimens are used:

"1. To indicate to the design engineer and to the draftsman the smoothness and appearance of various degrees of finish, and to permit the selection of an exact degree of smoothness for the functional purposes intended.

"2. To enable the shop mechanic to visualize the degree of roughness designated on a drawing.

"3. To enable the shop mechanic and inspector to inspect the product surfaces by comparing them with the proper specimen."

A profilometer which gives a direct reading of surface roughness on an indicating instrument was described by J. R. Wiencke, Physicists Research Company. He showed how this instrument, which makes use of a diamond-tipped stylus that moves over the surface under test, could be applied to test specimens of various shapes. The motions of the stylus are picked up electrically and amplified.

C. K. Gravley, Brush Development Company, described a surface analyzer, also an instrument of the tracer type, which provides a calibrated picture in the form of an oscillographic chart. The measuring head of the instrument consists of a "hill and

Members of the staff of the War Production Board were featured speakers and chairman of the combined session and conference on power generation at the AIEE summer convention. Conferring informally with A. C. Monteith (M'40), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. (second left), are (left) J. E. Moore (A'12) speaker; (second from right) W. L. Cisler (M'35) chairman, AIEE committee on power generation; and Edward Falck (A'40), speaker, all of War Production Board, Washington, D. C.

da[illegible]ystal pickup, which is moved over the [illegible]ace by a drive powered by a synchronous motor. The diameter-exploring finger at the end of the pickup carries a positioning shoe and a diamond tracer. The direct-recording oscillograph galvanometer employs another bimorph crystal as an electromechanical transducer. Its sensitivity is independent of frequencies below 60 cycles. A resistance-capacity-coupled three-stage amplifier permits calibrated vertical magnification of tracer-point motions up to 100,000 times, and chart speeds can be selected to give horizontal magnifications of 16, 80, and 400 times. The instrument is relatively simple to operate, he said.

Many questions on the construction and operation of the apparatus were answered by the speakers. The meeting served to acquaint the representatives of the electrical industry present with the status of recent developments in a field of measurement of great importance in the war production effort.

Lighting Aids to War Production Discussed at Conference

The part that good industrial lighting can play in winning the war was stressed at a conference on lighting aids to war production held Monday afternoon, June 22, 1942, during the AIEE summer convention at Chicago, Ill. About 85 persons were present.

Speaking on "What Engineered Lighting Can Do to Aid War Production," Professor J. O. Kraehenbuehl, University of Illinois, said that lighting sales programs of recent years had overemphasized the benefits of quantity, or foot-candles, at the expense of quality, or control of lighting. "If an individual in nutrition emphasized the caloric value of the food and neglected the vitamin content he would be doing what the lighting sales program has been doing the last few years," he said. "The emphasis on the value of those elusive elements in the food, the vitamins, has made the public conscious of some very essential life-giving materials, with the result that many people are living better and the normal wear and tear on the physical being has been reduced. If the same attitude were taken in lighting promotion, the lighting system would not be merely the source of lumens for foot-candles but would be a system for comfortable seeing."

Among essentials of the lighting system besides the quantity, the speaker listed the prevention of glare. "Direct glare from windows, or exposed lights in the line of vision is readily removed by covering the source to lower the brightness or by arrangement of the machines so that the offending source is not in the line of vision. The glare that comes indirectly to the eye, being reflected from either the work or machine or sometimes from some large specular surface within the angle of vision, usually may be removed by introducing low-brightness large-area sources. The point sources which are reflected from curved surfaces are very objectionable.

"Lighting should be uniform, since exposure to regions of high and low illumination requires continued adaptation. There should be good general lighting and, if necessary, supplementary lighting may be used to increase the illumination in special locations. The supplementary light should not be used unless it is uneconomical to reach the higher level of illumination with general lighting, and when it is used there must be a proper balance between the work brightness and the brightness of the surrounding field. Where the illumination is uniform and the vertical component is high there will be few shadows to cause accidents.

"If the lighting installation is properly engineered the workman will be able to produce more efficiently," Professor Kraehenbuehl declared. "He will be able to maintain this production throughout the period of emergency. If the worker is happy in his surroundings his morale will be high, and lighting contributes more to pleasant surroundings than does any other factor in the plant. Saving in spoilage and lack of absences are as great aids to production as is the producing of more pieces, and in addition heighten morale, since injury in either the physical or mental sense is detrimental to the morale of the individual involved and to those associated with him. Good lighting helps the individual who is necessarily slower or has defective eyes. With the call for younger men for combat service much of the production must be carried by the older men who, because of age, are slower and have a higher percentage of defective vision.

"For efficient production, we must add to our promotion of more lumens the element of proper use of those lumens on the work surface."

The timely question of "Substitute Materials for Industrial Lighting Equipment" was discussed by E. D. Tillson, Commonwealth Edison Company. The substance of Mr. Tillson's talk is scheduled for publication in a later issue of *Electrical Engineering*. A. K. Gaetjens, General Electric Company, spoke on "Maintaining Lighting in War Industries." His talk is to be published in a forthcoming issue of *The Magazine of Light* published by his company.

The relation of "Good Industrial Lighting and Safety" was described by J. M. Roche, National Safety Council, who declared that accidents caused entirely or partly by improper illumination represented between 15 and 25 per cent of all industrial accidents in 1941. The total of all such accidents resulted in the estimated loss of 108,000,000 man-days of production time.

Two factors were pointed out as at fault in connection with industrial lighting and accidents: substandard installations and poor maintenance. From the standpoint of the safety engineer, it was stressed that industrial lighting systems should be designed only by lighting experts, not by plant maintenance men or others not entirely familiar with the problems to be met with and overcome.

Daylight illumination was specified as ideal for most industrial operations; however, it is recognized that daylight illumination is impracticable except in a few cases. With the increase of three-shift work, the demand for good artificial lighting systems has greatly increased. The requisites for such a system include:

1. Adequate light for each employee so that he can see clearly, without fatigue or eyestrain, the work which he is doing.
2. All lighting equipment selected and installed to avoid eyestrain.
3. Lights placed so sharp shadows will be avoided on important parts of work. Lamps equipped with reflecting and diffusing devices to soften shadows and avoid glare.
4. An adequate level of general illumination sufficient to avoid the use of local illumination wherever possible.

Other factors that must be taken into consideration include the voltage of the system, the wiring, the illumination level to be maintained, the reflectors to be installed, the room conditions and maintenance requirements, and the types of lamps used.

A periodic system of maintenance for all lighting equipment in the plant should be installed and adhered to rigidly, the speaker said. Decreases in the efficiency of lighting systems of from 20 to 60 per cent were cited, and it was stressed that the efficiency of the lighting system could be maintained to approximately 80 per cent of the original installation through the application of systematic maintenance.

Mr. Roche proposed that the AIEE and the Illuminating Engineering Society work with the National Safety Council in developing information on the lighting and accident problem. His proposal included the study of plant accident records prior to and following the installation of improved lighting systems.

Professor H. B. Dates, chairman of the committee on light in wartime of the Illuminating Engineering Society, described the activities of the IES to aid war production, and especially its work in the development of lighting standards. The timely publication of "American Recommended Practice for Industrial Lighting," which was approved by the American Standards Association March 17, 1942, is the culmination of a series of studies of industrial seeing tasks initiated by the IES through its committees in 1935. Representatives of 23 organizations including AIEE co-operated in its production.

"With round-the-clock operation the rule rather than the exception, good lighting for the seeing tasks of industry is more important than ever before," Professor Dates pointed out, referring to wartime operations. He reviewed in some detail the principal topics covered by the new Standard, and also called attention to another American Standard sponsored by the IES and approved by ASA February 27, 1942, ("Illuminating Engineering Nomenclature and Photometric Standards") which is pertinent to all work on the subject of illumination. Both Standards may be secured from ASA headquarters, 29 West

39th Street, New York, N. Y., or IES headquarters, 51 Madison Avenue, New York.

Meeting of District 4 Executive Committee at Chicago

The Southern District (4) delegates and members present at the 1942 summer convention at Chicago, Ill., held a luncheon meeting on June 23, 1942, which served as a District executive committee meeting. Those who attended were:

J. E. Housley, vice-president, East Tennessee
C. L. Crosby, Virginia
J. P. Hamilton, Muscle Shoals
J. R. Smith, Louisville
N. C. Pearcy, Chicago
J. P. Argo, Memphis
E. A. Bureau, Louisville
E. E. Kilburn, North Carolina
E. W. O'Brien, Georgia
D. R. Baldwin, East Tennessee
A. P. Farrow, East Tennessee
Mark Eldredge, Washington, D. C.
Mead Warren, Jr., East Tennessee
Robert C. Hill, Virginia
Stanley Warth, Florida
J. V. Hay, New Orleans
C. W. Ricker, New Orleans
Wm. J. Miller, Alabama
A. S. Hoefflin, District secretary, Louisville

Plans for the proposed District meeting in Virginia in 1943 were discussed but were held in abeyance because of the curtailment of transportation and the difficulty in securing hotel accommodations. The next District executive committee meeting will be held in Memphis, Tenn., in the fall, providing transportation facilities permit. Among other District and Section affairs discussed was the possibility of holding District meetings jointly with student conferences.

AIEE Board of Directors Meets During Summer Convention

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at the Drake Hotel, Chicago, on June 24, 1942.

The committee on planning and co-ordination gave a progress report of its study of Institute activities in relation to war needs, and expects to pursue its consideration of this subject and report more fully at the August board meeting. In connection with it, there were presented interim recommendations of the technical program committee along this line, which were approved by the board for immediate application. These recommendations were to the effect that a normal schedule of national conventions and District meetings should be planned, all strictly business in character; where appropriate, local conferences or production clinics may be held under Section auspices, so planned as to require a minimum of traveling for those attending; technical programs and papers should be closely related to the war effort, and programs in general should present practical recommendations, or results of experience, in such forms as will be of most use to those engaged in war production or planning; papers of not sufficient value to the war effort, and papers which cannot be published for censorship reasons, will be held in abeyance for presentation and publication after the emergency.

Upon recommendation of the finance committee, an increase of $5,000 in the appropriation for printing the advertising section of *Electrical Engineering* was voted, to meet the increased printing expense due to advertising revenue in excess of that estimated for the year, and $1,500 was added to the appropriation for printing miscellaneous publications (a self-liquidating item), because of increased demand for Institute publications. Provision was made for the attendance of one or two delegates of the University of Alberta Branch to the joint conference on student activities to be held in Vancouver, in September, during the Pacific Coast convention.

Upon recommendation of the publication, technical program, and finance committees, authorization was given for the issuance as a special publication of the Institute on a self-liquidating basis of a "Bibliography of Electrical Safety Literature, 1930–1941," submitted by the committee on safety.

The board approved the following, as recommended by the Standards committee:

Submission to ASA for approval as an American Standard, of the revision of AIEE Standard No. 4, "Measurement of Test Voltages in Dielectric Tests," which was approved by the board at its May meeting.

A new AIEE Standard, "Apparatus Bushings," developed by a joint committee of the AIEE and the Edison Electric Institute.

A revision of present AIEE Standard No. 22, "Air Switches and Bus Supports," developed by the committee on protective devices.

Revisions of the following four American Standards, which comprise the Sectional Committee project, "Graphical Symbols," for which the AIEE and The American Society of Mechanical Engineers are joint sponsors:

Graphical Symbols for Welding, Z32.1

Graphical Symbols for Electric Power Control and Measurement, Z32.3

Graphical Symbols for Telephone, Telegraph, and Radio Use, Z32.5

Electrical Symbols for Architectural Plans, Z32.9

A brief report was given of the work of the Standards committee which may be considered as aiding the war effort, as evidenced by increased activity of committees engaged in the development of Standards, and increased sales of AIEE Standards, particularly the Marine Rules. The recent development of "Guides for Operation" of transformers and regulators is a direct instance of work accomplished which permits of apparatus under overload conditions now necessary on many installations.

H. S. Osborne tendered his resignation as an AIEE representative on the Electrical Standards Committee of the American Standards Association, and the president was empowered to appoint his successor.

The resignation of W. S. Barstow as a representative of the Institute on the Engineering Societies Library Board was presented and accepted. The appointment of his successor was referred to the president with power.

Upon recommendation of the District meeting committee, authorization was given for the postponement to the earliest propitious time of the Middle Eastern District meeting, previously scheduled to be held in Pittsburgh, Pa., in October 1942.

Other actions taken by the board included the following:

Minutes of the meeting of the board of directors held May 22, 1942, were approved.

A report of a meeting of the board of examiners held June 18, 1942, was presented and approved. Upon recommendation of that board, the following actions were taken: 4 applicants were transferred and 1 was elected to the grade of Fellow; 21 applicants were transferred and 16 were elected to the grade of Member; 108 applicants were elected to the grade of Associate; 80 Students were enrolled.

Disbursements for June, amounting to $27,315.92, were reported by the finance committee and approved by the board of directors.

Those present were:

President—David C. Prince, Schenectady, N. Y.

Past President—F. Malcolm Farmer, New York, N. Y.

Vice-Presidents—J. L. Hamilton, St. Louis, Mo.; K. L. Hansen, Milwaukee, Wis.; N. S. Hibshman, Bethlehem, Pa.; J. Elmer Housley, Alcoa, Tenn.; Arthur L. Jones, Denver, Colo; Everett S. Lee, Schenectady, N. Y.; Walter C. Smith, San Francisco, Calif.; A. LeRoy Taylor, Salt Lake City, Utah.

Directors—T. F. Barton and H. S. Osborne, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair and L. R. Mapes, Chicago, Ill.; F. J. Meyer, Oklahoma City, Okla.; W. B. Morton, Philadelphia, Pa.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter, New York, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

By Invitation: Officers-Elect—A. G. Dewars, Minneapolis, Minn.; C. R. Jones, New York, N. Y.; E. T. Mahood, Kansas City, Mo.; K. B. McEachron, Pittsfield, Mass.; E. W. Schilling, Bozeman, Mont.

AIEE Radio Program Expanded in Co-operation With Other Societies

The success of the Institute's 1941 series of radio broadcasts led the AIEE Board of Directors at its August 1941 meeting to authorize President Prince to appoint a committee of three AIEE members to approach other engineering societies with a proposal for joint sponsorship of a new and broader program of radio broadcasts, covering the work of the engineer in various fields. The proposal ultimately won the co-operation and financial support of the American Society of Civil Engineers, The American Society of Mechanical Engineers, and the American Institute of Chemical Engineers. Accordingly, a joint committee of three representatives from each of these societies was established, with AIEE Vice-President E. S. Lee as chairman.

This joint committee went to work in the fall of 1941 and, with the consultation and advice of Doctor James Rowland Angell, public service counselor for the National Broadcasting Corporation, began the development of a program intended to reflect the varied contributions of engineers to the prosecution of the war effort. The

Japanese assault on Pearl Harbor stimulated the activity, especially with reference to completion of the work that had been started on script concerning blackouts, bombs, and explosion damage to structures.

As indicated in the accompanying schedule for the broadcasts, all material is being prepared by or under the direction of eminent authorities. The National Broadcasting Company and the Office of Civilian Defense have endorsed the program and given generous help in the preparation and approval of scripts. The program, as announced June 29, is given in the accompanying tabulation.

The Engineer at War

Broadcasts 6:30 to 6:45 p.m. NBC Network

1. July 16. Blackouts. Representative of the Office of Civilian Defense and S. G. Hibben (A'34) Westinghouse Electric and Manufacturing Company.

2. July 23. Protection Against Incendiary Bombs andgGas. Sidney D. Kirkpatrick, president, American Institute of Chemical Engineers, and Doctor Arthur Ray.

3. July 30. The Resistance of Structures. Professor H. E. Westman, New York University, and Walter D. Binger, commissioner of Borough Works, Manhattan.

4. August 6. The Navy; Ships. Admiral S. M. Robinson.

5. August 13. Dry Docks and Ship-Repair Bases. Rear Admiral Ben Moreell.

6. August 20. Tanks and Tools Prepared by the Chrysler Corporation.

7. August 27. Airplanes. Prepared by the Wright Aeronautical Corporation.

8. September 3. Petroleum Production. Prepared by Robert E. Wilson, president, Pan American Petroleum Company.

9. September 10. Power, Hydro and Steam Electric. Glen B. Warren, General Electric Company, and others.

10. September 17. United States Engineers Corps in Peace and War.

11. September 24. Communications in Action.

ABSTRACTS • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE Pacific Coast convention, Vancouver, B. C., September 9–11, 1942, and are expected to be ready for distribution in advance pamphlet form within the current month. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the convention registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Basic Sciences

42-152—History of A-C Wave Form, Its Determination and Standardization; *Frederick Bedell (F'26). 15 cents.* With the birth of the transformer and the first distribution of alternating currents, interest in wave form grew and methods were developed for its determination, chiefly point-by-point method of instantaneous contact, mechanical oscillograph, cathode-ray oscillograph, and the oscilloscope with stabilized time-axis. The point-by-point method, by which were made the first major contributions, is now practically superseded by oscillograph and oscilloscope, each finding increasing use in its field. With the determination of wave form accomplished, demand arose for its standardization corresponding to expanding applications. No single standard being suited to all applications, different standards have been developed in different fields, as in power, communication, and insulation. While it is desirable that standards, once set up, remain fairly stable, they should be subject to review and occasional change to keep in step with technological advances. Minor revision in communication is in progress. Although standards in other fields do not appear ideal, revision may be deferred.

42-158—Inverse Functions of Complex Quantities; *H. B. Dwight (F'26). 15 cents.* Formulas for inverse functions of complex quantities such as $\sin^{-1}(x + iy)$, are of use in several branches of electrical engineering. Calculations for transmission circuits require them, particularly in connection with communication circuits. Integration of expressions involving complex quantities can involve inverse functions. They are encountered also in conformal transformations. In presenting the formulas in this paper, it is necessary to specify angles with sufficient detail to avoid ambiguity and the liability of incorrect results. Also, all of the appropriate multiple values should be included. It is not always obvious by inspection that two different complex values are only values of different branches of the same function and are both correct. In all cases, numerical examples are given as illustrations.

Electrical Machinery

42-156—Interim Report on Guides for Overloading Transformers and Voltage Regulators; *transformer subcommittee of the AIEE committee on electrical machinery. 15 cents.* The present war emergency has crystallized the need for additional information concerning the maximum load capability of modern-design transformers and voltage regulators in order that these apparatus may be utilized to a greater extent for meeting present and new load requirements with a minimum amount of new equipment, thus conserving critical war materials. The relation between the life expectancy of insulation as indicated by laboratory tests and the actual life of a transformer is largely theoretical so that the use of such information must be tempered by sound judgment based on operating experience. This report represents a compromise of views that is considered conservative and satisfactory for immediate general use subject to the limitations and cautions given herein. Consideration is given to operation with normal life expectancy and also with moderate sacrifice in life expectancy, thus taking into account the effect of the following factors:

a. Characteristics and limitations of the apparatus involved

b. Ambient temperature

c. Load factor

d. Supplemental cooling

e. Sacrifice of life expectancy

Industrial Power Applications

42-154—Application of Vacuum-Tube Oscillators to Induction and Dielectric Heating in Industry; *J. P. Jordan. 15 cents.* High-frequency inductive and dielectric heating has in recent years become a very important factor in industry. Frequencies up to 1,000,000 cycles are used for inductive heating and from 1,000,000 to 30,000,000 cycles for dielectric heating. The lower frequencies are most generally used for forging and melting; intermediate frequencies (obtained from rotating machines) are used in practically all heating processes; the higher frequencies (obtained from spark-gap and vacuum-tube oscillators) are used for surface-hardening small or irregularly shaped parts and for heating low resistance metals for brazing and soldering. For the heating of nonmetallic materials such as plywood and plastics by the dielectric loss method, vacuum-tube oscillators must be used because of the high frequencies involved. In inductive heating, the heat is generated largely by eddy currents induced in the surface of the metal. Using this effect, vacuum-tube oscillators have made possible many new applications in the fields of surface hardening, brazing, and soldering. Its advantages are extreme localization of the heat, speed, cleanliness, and uniformity of results.

Power Transmission and Distribution

42-146—A Practical Discussion of Problems in Transformer Differential Protection; *P. W. Shill. 25 cents.* The war has brought about more insistent demands for relay systems of high degrees of reliability and selectivity. At the same time, much obsolete equipment is being reconditioned and put back into service, while the usual supplies of suitable material and equipment to build first-class protective systems have been largely curtailed or completely denied to the engineers responsible for relay protection. The question of the current differential protection of transformer banks is discussed from the simplest to complex cases. The protection of three-phase delta-zigzag-wye transformer banks, and the protection of three-phase to two-phase

Future AIEE Meetings

Pacific Coast Convention
Vancouver, B. C., September 9–11, 1942

Winter Convention
New York, N. Y., January 25–29, 1943

Scott-connected transformer banks are discussed, for what is believed to be the first time. Tolerances and compensating factors which can be made use of in the design of transformer differential protections are discussed, and specimen tables have been worked out. The use of ordinary overcurrent relays for transformer differential protection is discussed with special application to systems of small generating capacity.

42-148—Design, Manufacture, and Installation of 120-Kv Oil-Filled Cables in Canada; *D. M. Farnham, O. W. Titus (M'36). 25 cents.* This paper describes the 120-kv oil-filled cable system of the Montreal Light, Heat, and Power Consolidated, installed during 1941 and in present operation as a link in a large interconnection scheme. The paper describes the functions of the various sections of the system and the reasons for the choice of this method of effecting the interconnection. The steps required in designing the cable system are outlined and the general principles governing each such step discussed. A short section dealing with manufacture is followed by a section covering the organization required for installation and the methods followed. The final section deals with operating practice, especially the basis of loading.

42-149—Method for A-C Network Analysis Using Resistance Networks; *W. E. Enns (A'37). 20 cents.* A new method of calculating a-c network problems is described and illustrated with a practical example. The scope of the present paper is limited to the use of the conventional d-c calculating board for making load distribution and voltage studies for three-phase networks with balanced loading. In contrast with the a-c network analyzer this method is not inherently exact, but by successive approximations an exact solution may be obtained. Fortunately, the first approximation gives results of sufficient accuracy for most practical problems and rarely is it necessary to carry the solution beyond a second approximation. The practical example in the paper shows that the procedure is simple and also quicker than other methods of analyzing complex networks with the exception of the a-c analyzer. Therefore the new method should become a useful tool for engineers in system planning work.

42-150—Power System Interconnection in Quebec; *W. R. Way. 25 cents.* The paper describes the development of three of the large power systems in the Province of Quebec, which, due to the urgent demand for prime power for defense purposes, have been suitably interconnected. These systems are supplied exclusively from hydroelectric plants, and it is pointed out that the load characteristics and power available on each subsystem are not ideally matched, but when operated as an integrated system, these characteristics become complementary. A study of the problem, illustrated by means of curves, indicates that when operated as an interconnected group, 18 per cent of the total power resources may be reclaimed and made available for sale as prime power. This surplus would otherwise be wasted or disposed of as electric-boiler power, and reference is also made to control of reactive power, voltage, frequency on the interconnected system, as well as to stability and short-circuit problems. Total resources on the combined system to the extent of nearly 4,000,000 horsepower are involved.

42-153—Three-Winding Transformer Ring Bus Characteristics; *G. W. Bills (A'38), C. A. MacArthur. 15 cents.* For generating stations sending large blocks of power over several high-voltage transmission lines the use of three-winding transformers connected so as to form a ring bus on the low-voltage side with no high-voltage bus or breakers offers certain advantages. Studies were made on a network analyzer to determine power limits and fault currents on a system having a three-winding transformer ring bus. Then, for comparison, similar studies were made on the same transmission system using a standard high-voltage bussing arrangement. The studies indicate that the transient power limits are practically independent of the reactance between low-voltage windings as it varies from 0 to 40 per cent. The use of the higher reactance gives equal or lower short-circuit currents than are obtained on the standard system, while the transient stability power limits are nearly 10 per cent higher.

Protective Devices

42-147—A New Single-Pole Service Restorer; *E. E. Tugby. 15 cents.* With the advent of increased rural electrification there has come a definite requirement for high quality service at the lowest possible cost. The single-pole service restorer described in this paper is a marked advance in protective equipment and has a number of features not heretofore found in equipment of its general type, at a very low first cost. The operating energy of the device is contained in a spring, which is rewound after each operation by a motor of unique and interesting design. This motor has no commutator and needs no secondary source of operating energy, as the operating coils are in series with the primary line. Maximum use is made of all component parts and in one case, a device performs two functions. The use of this new restorer will allow closer co-ordination on rural electric systems and will make available a much higher class of service than available heretofore. Adjustments are provided that make this unit a very flexible device.

ACO–42-151—Some Canadian Developments in Relays and Relay Applications; *E. G. Ratz (A'19). 20 cents.* The paper describes features of some Canadian relay developments, among which are the necessity of selecting proper value of generator field discharge resistance to obtain maximum speed of protection; a relay to protect generators on short circuit when the short-circuit current may be less than full-load current; a self-resetting over voltage protection; a method of detecting field circuit grounds; experience with simple transformer protection arranged to give high speed on heavy faults; performance of coupling capacitors on sudden drop and recovery of line voltage; methods of using impedance relays to give faster than timed protection in the "end zones"; and use of and experience with impedance relays for phase-to-ground protection.

42-155—Design and Operation of High-Voltage, Axial Air-Blast Circuit Breakers; *A. K. Leuthold. 20 cents.* For selective protection of interconnected high-voltage transmission systems, fast operating circuit breakers are of great importance and as a large proportion of the system faults are of a transient nature, the system stability can be considerably increased by fast tripping and high-speed reclosing of the faulty phase only. Experiences have shown that compressed air is most suitable for arc-extinction and fast breaker operations. This paper presents the design and operation experiences of 150 kv and 220 kv axial air-blast circuit breakers and illustrates an air-blast breaker suitable for extremely high voltages and rupturing capacity, achieved from extensive research work and operation experiences. This particular breaker design, which consists of potential-controlled, multiple arc-breaks, guarantees equal voltage distribution between the different arc-breaks and therefore permits, in spite of the present limited test plants, judging the breaker performance under full rated breaking capacity.

42-157—Some Air-Blast Circuit-Breaker Installations in Canada; *H. W. Haberl (A'28), R. A. Moore. 15 cents.* This paper is intended to show pictorially a number of air-blast circuit-breaker installations in Canada in the range of from 4 to 230 kv. Of the various types of circuit breakers discussed in this paper, there are in service in Canada 23 air-blast breakers of the 69-, 138-, and 230-kv types. There are also in operation 37 breakers on 13- and 4-kv service. Numerous short-circuit tests and oscillograms have been incorporated in the paper. These tests justify the manufacturer's interrupting ratings of some of the types of air-blast breakers shown.

PERSONAL ....

H. N. Blackmon (M'32) manager of the Westinghouse Editorial Service, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been presented the Westinghouse Order of Merit for his "outstanding ability to interpret Westinghouse engineering achievements to editors of technical and trade magazines and for his honesty of opinions and ability to teach editorial techniques and philoso-

phy." He has been with the company since 1925. **R. E. Marbury** (M'36) section engineer, capacitor section, switchgear engineering department, also was awarded the Order of Merit for his "advanced engineering ideas." **James Boyd** (M'40) eastern district manager, New York, N. Y., likewise was honored "for his clearsighted, practical sales ability in serving a complicated metropolitan area; for his management of a sales organization under difficult conditions existing in that area; and for his personal salesmanship and courage in handling large and difficult negotiations." He joined the company in 1917. **R. C. Bergvall** (A'24, M'41) assistant to the vice-president in charge of engineering at Pittsburgh, Pa., also has been cited "for his broad knowledge of the design, application, and performance characteristics of Westinghouse apparatus and for his ability to co-ordinate and guide engineering efforts and activities to the best interest of the company." He joined the company in 1921. **C. W. Drake** (A'20, M'21) manager, general mill section, industry engineering department, East Pittsburgh, Pa., likewise has been honored for "his broad knowledge and appreciation of the electrical problems of industry and his ability to analyze, explain, and solve them, and for his unstinting efforts and excellent success in the instruction of younger men." He has been employed by the company since 1905.

W. R. Work (A'07, F'40) head of the electrical engineering department, Carnegie Institute of Technology, Pittsburgh, Pa., has been appointed assistant director of the college of engineering. He was born at Steelton, Pa., on May 4, 1881, and received the degree of bachelor of arts from Wittenberg College in 1902 and that of master of engineering in electrical engineering from Ohio State University in 1905, as well as the honorary degree of doctor of science from Wittenberg College in 1920. After a year with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he became instructor in electrical engineering at Carnegie Institute of Technology in 1906. He became assistant professor in 1909, associate professor in 1915, and professor in 1921. During 1920–21 he was acting head of the department of electrical engineering in addition to serving as consulting electrical engineer with Morris Knowles, Inc., Pittsburgh, Pa., and in 1921 he was made head of the department of electrical engineering. From 1921 to 1930 he also maintained private practice as a consulting electrical engineer. He is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu, as well as the American Association for the Advancement of Science and the Society for the Promotion of Engineering Education.

M. L. Manning (A'36, M'42) research engineer, insulation development section, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has been appointed associate professor of electrical engineering at Illinois Institute of Technology, Chicago. He received from South Dakota State College in 1927 the degree of bachelor of science and that of master of science from the University of Pittsburgh in 1932. He joined the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1927 and after a year as designer of electric apparatus with the Sullivan Machinery Company, Claremont, N. H., returned to the Westinghouse Electric company as industrial motor engineer. In 1932 he joined the mathematics department of the University of Pittsburgh as instructor. He continued graduate work in mathematics and in 1936 returned to the Westinghouse Electric and Manufacturing Company as transformer design engineer, instrument transformer section, Sharon, Pa. In 1937 he was appointed supervisor of the high-voltage laboratories and Westinghouse lecturer in electrical engineering on the staff of the University of Pittsburgh. He has been serving currently as chairman of the AIEE Sharon Section.

J. F. Toomey (A'19) of the switching development department, Bell Telephone Laboratories, Inc., New York, N. Y., retired on April 30, 1942. He was born on April 9, 1878, at Boston, Mass. From 1892 to 1900, he was associated with the New England Telephone and Telegraph Company, Boston, Mass., and in 1900 he joined the engineering department of the Roland Oakes Company, Holyoke, Mass. He returned to the engineering department of the New England Telephone and Telegraph Company, Boston, Mass., in 1901 and in 1904 joined the engineering department of the American Telephone and Telegraph Company, Boston, Mass. He was transferred later to that company's New York office. In 1919 he entered the department of development and research, where he worked on the development of toll circuits and long-distance projects. In 1925 he became associated with the Bell Telephone Laboratories and was placed in charge of the analysis of toll systems in the toll development department. Later, in the switching development department he worked on special problems relating to toll switching systems. He holds a number of patents on communications devices.

A. W. Henshaw (A'06, F'13) General Electric Company, Schenectady, N. Y., retired recently. He was born August 19, 1872, at Easthampton, Mass., and was graduated from Lehigh University with the degree of electrical engineer in 1894. In 1895 he was employed in the laboratory of the Electro-Dynamic Company, Philadelphia, Pa., and in 1896 he joined the testing department of the General Electric Company, Schenectady, N. Y. He was transferred in 1897 to the engineering department, where he worked on the design of induction motors. In 1903 he was appointed commercial engineer in the industrial department and in that year went to Pittsfield, Mass., as commercial engineer in charge of induction motors for the Stanley Electric Manufacturing Company, which later became the Pittsfield works of the General Electric Company. He returned to the General Electric Company, Schenectady, N. Y., as a member of the engineering department in 1907 and later joined the induction motor and manufacturing general departments. In 1925 he was transferred to the commercial general department, and later was placed in charge of all General Electric association relationships.

E. M. Wood (A'09, M'25) planning engineer, Hydro-Electric Power Commission of Ontario, Toronto, and co-author with A. H. Frampton (M'28) of the paper, "The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario," has received the 1941 AIEE District 10 prize for best paper. He was born on May 21, 1882, at Norfolk County, Ont., and received the degree of bachelor of applied science from the University of Toronto in 1908. He joined the Hydro-Electric Power Commission in 1909 as an inspector and from 1910 to 1913 he was assistant to the superintendent of construction. In 1913 he became engineer in charge of the complaint section, engineering department, Canadian General Electric Company, Toronto, Ont., and from 1917 to 1919 he was superintendent of the power section and safety engineer, Consolidated Mining and Smelting Company, Trail, B. C. In 1919 he returned to the Hydro-Electric Power Commission of Ontario as assistant engineer, station section, electrical engineering department. He served as chairman of the AIEE Toronto Section, 1928–29.

D. D. Ewing (A'11, F'21) professor of electrical engineering, Purdue University, Lafayette, Ind., has been appointed head of the school of electrical engineering and director of the electrical laboratory. He was born at Vanlue, Ohio, October 7, 1883, and was graduated in 1906 with the degree of mechanical engineer from Ohio Northern University, from which he received the honorary degree of doctor of engineering in 1936. After serving as an assistant engineer with the Missouri Pacific Railway, St. Louis, and the Hocking Valley Railway, Logan, Ohio, he became professor of electrical and mechanical engineering at Ohio Northern University, Ada, Ohio, in 1907. He was appointed assistant professor of electric railway engineering at Purdue University in 1913, later becoming associate professor, and in 1918 becoming professor. Since 1910 he has also been a consulting engineer. He is the coauthor of a book, "Electric Railway Engineering" and the author of a number of technical articles. He is also a member of the Society for the Promotion of Engineering Education and Eta Kappa Nu.

E. W. Boehne (A'29, M'37) research engineer, power circuit breaker engineering department, General Electric Company,

Philadelphia, Pa., has received the 1941 AIEE District 2 prize for best paper for his paper, "The Geometry of Arc Interruption." He was born on June 2, 1905, at Laramie, Wyo., and received the degree of bachelor of science in 1926 from Texas Agricultural and Mechanical College, and that of master of science in 1928 from Massachusetts Institute of Technology. He was employed by the General Electric Company, Lynn, Mass., from 1926 to 1928, when he was transferred to the company's high-voltage engineering laboratory at Pittsfield, Mass. Later in 1928 he went to Schenectady, N. Y., where he was employed in the engineering general department until 1933 when he joined the switchgear engineering department at Philadelphia. He was later transferred to the circuit-breaker engineering department. He received honorable mention in the selection of outstanding young engineer for 1936 by Eta Kappa Nu. He is also a member of the Franklin Institute.

H. M. Shockley (A'25) assistant switchgear sales engineer, Canadian General Electric Company, Ltd., Toronto, Ont., has been awarded the 1941 AIEE District 10 prize for initial paper for his paper, "The Selection of Switchgear for Industrial Plants." He was born at Macclesfield, England, on March 18th, 1901, and received the degree of bachelor of applied science in electrical engineering from the University of Toronto in 1922. In that year he entered the test department of the Canadian General Electric Company, Ltd., Peterboro, Ont., and from 1924 to 1926 he was engaged in switchgear design. In 1936 he was transferred to the switchgear sales engineering department at Toronto. After being associated with A. J. F. Montabone, consulting engineer, Montreal, P. Q., from 1929 to 1935, he returned to the switchgear-application and sales department of the Canadian General Electric Company.

J. H. Cox (A'25) section engineer, mercury-arc rectifier engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., co-author with H. C. Myers of the paper, "Excitation Circuits for Ignitron Rectifiers," has been awarded honorable mention in the 1941 AIEE national prize award for best paper in engineering practice. He received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1923. From 1917 to 1919 he was in the marine engineering department of the United States Navy. In 1923 he joined the service department of the Westinghouse Electric company with headquarters at New York and in 1924 he was transferred to the porcelain insulator and transmission department at East Pittsburgh. Since 1929 he has been engaged in the development and design of power mercury-arc rectifiers.

A. H. Frampton (A'21, M'28) assistant electrical engineer, Hydro-Electric Power Commission of Ontario, Toronto, and co-author with E. M. Wood (M'25) of the paper, "The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario," has received the 1941 AIEE District 10 prize for best paper. He was born on May 23, 1899, at Gillingham, Kent, England, and was graduated from the University of Toronto in 1925 with the degree of bachelor of applied science. He was engaged in construction and installation work with the G. J. Beattie Company, Toronto, Ont., from 1915 to 1917, when he became laboratory assistant with the Hydro-Electric Power Commission of Ontario. After studying at the University of Toronto (1921–25) he returned to the electrical-engineering department of the Hydro-Electric Power Commission in 1925.

I. A. Terry (A'27; F'37) works manager's office, General Electric Company, Schenectady, N. Y., has been made general assistant to the vice-president in charge of design engineering, apparatus department. Born in Ogden, Utah, on October 31, 1903, he received the degrees of bachelor of science in electrical engineering from the University of Utah in 1925 and master of science in electrical engineering from Union College in 1929. In 1925 he entered the student test course, General Electric Company, Schenectady, N. Y., and in 1927 was transferred to the a-c engineering department. From 1930 to 1933 he worked on the development and research in the a-c engineering department and in 1933 he became assistant engineer in the motor and generator engineering department. In 1940 he was appointed assistant in the office of the works manager.

Earle Wild (A'27, M'36) load dispatcher, Commonwealth Edison Company, Chicago Ill., has received honorable mention in the 1941 AIEE national prize award for best paper in engineering practice for his paper, "Methods of System Control in a Large Interconnection." He was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in electrical engineering in 1924. In that year he joined the Commonwealth Edison Company as station operator at the northwest station. From 1928 to 1930 he was assistant efficiency engineer and from 1931 to 1935 he was load dispatcher. In 1935 he became technical assistant to the chief load dispatcher, working on the study of interconnection operating and automatic load-control problems.

T. A. Rich (A'41) electrical engineer, general engineering laboratory, General Electric Company, Schenectady, N. Y., has received the 1941 AIEE District 1 prize for best paper and initial paper for his paper, "Ampere-Squared-Second Recorder." He was born on June 18, 1905, at Lynn, Mass., and received the degree of bachelor of science in electrical engineering in 1930 from Harvard University. From 1923 to 1927 he was employed in the standardizing laboratory of the General Electric Company, in West Lynn, Mass. In 1930 he joined the carrier-current section of the radio department, General Electric Company, Schenectady, N. Y., and in 1933 was transferred to the general engineering laboratory. He is the holder of numerous patents.

E. H. Eacker (A'25) assistant to the president, Boston (Mass.) Consolidated Gas Company, has been elected vice-president in charge of the electrical division and investigating department. He was born at Buffalo, N. Y., on December 15, 1899, and received the degrees of bachelor of science and master of science from Massachusetts Institute of Technology in 1923. He was employed by the General Electric Company from 1920 to 1923, when he became assistant superintendent of electric distribution, Charlestown (Mass.) Gas and Electric Company. He was made superintendent in 1925 and local manager in 1930. He was appointed assistant to the vice-president in charge of the Boston District, Boston Consolidated Gas Company, in 1931, and in 1936 was made assistant to the president.

H. Y. Hall (A'03, F'27) former superintendent of Waterside station, Consolidated Edison Company of New York (N. Y.), has been appointed production superintendent. He has been with the company and its predecessor, the United Electric Light and Power Company, since 1921. **H. A. Bauman** (A'26, M'41) assistant superintendent, production department, Brooklyn (N. Y.) Edison Company, has become electrical superintendent. He was employed by the New York Edison Company in 1926, remaining as assistant superintendent of the Waterside station when that company became a part of the Consolidated Edison Company of New York in 1936. He joined the Brooklyn Edison Company in 1938.

D. S. Hilborn (A'06, M'40) senior staff engineer, general engineering department, Eastern area, Bell Telephone Company of Pennsylvania, Philadelphia, retired recently. He was born on March 19, 1877, in New Orleans, La., and received the degree of bachelor of science in electrical engineering in 1899 from the University of Pittsburgh. From 1899 to 1912 he was engaged in field work, construction, and maintenance for the Bell Telephone Company of Philadelphia and the Bell Telephone Company of Pennsylvania, and from 1912 to 1917 he was testing engineer, plant department, with the latter company. In 1917 he became assistant engineer, general engineering department, and in 1926 senior staff engineer.

J. D. McCrumm (A'36) assistant professor of electrical engineering, Swarthmore (Pa.) College, has received the 1941 AIEE District 2 prize for initial paper for his paper, "An Experimental Investigation of Subharmonic Currents." He was born at Colorado Springs, Colo., on April 17, 1912,

and received the degrees of bachelor of science in electrical engineering in 1933 and master of science in 1934 from the University of Colorado. In 1934 he entered the test course of the General Electric Company, Schenectady, N. Y., and in 1935 became instructor in electrical engineering at Swarthmore College. He is also a member of the Society for the Promotion of Engineering Education.

W. H. Norman (A'39) operation and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been appointed staff engineer in that department. He was born in New York, N. Y., on December 17, 1895, and received the degree of bachelor of science from Carnegie Institute of Technology in 1917. From 1920 to 1926 he was engineering assistant with the Chesapeake and Potomac Telephone Company, Washington, D. C. In 1926 he joined the American Telephone and Telegraph Company as engineer and in that capacity worked on engineering cost studies. In 1930 he was transferred to the operating results division.

B. W. Pike (Enrolled Student) co-author with L. K. Davis of the paper, "Localized Annealing of Rock-Bit Bodies by Sixty-Cycle Induction Heating," has received the 1941 AIEE District 7 prize for Branch paper. He was born at Trinity, Tex., on October 2, 1914, and received the degree of bachelor of science in electrical engineering in 1942. After being associated with the Shell Oil Company as radio technician in the geophysical research laboratory for two years, he joined the Reed Roller Bit Company, Houston, Tex., working there while studying at Rice Institute. He is currently engaged in research on a high-frequency induction process.

R. E. Hedges (Enrolled Student) has received the 1941 AIEE District 8 prize for Branch paper for his paper, "An Electrical Method for Automatic Musical Transposition." He was born at New Philadelphia, Ohio, on August 16, 1920, and has been a student at the University of Southern California since 1938. He plays several musical instruments, and his study of music prompted the development of the device which is the subject of his paper. At present, he is working in the electrical research department of the Douglas Aircraft Company, Inc., Santa Monica, Calif. He is also a member of Eta Kappa Nu and Sigma Xi.

G. B. Tebo (A'36) testing engineer, Hydro-Electric Power Commission of Ontario, Toronto, has received honorable mention in the AIEE 1941 national prize award for initial paper for his paper, "Measurement and Control of Conductor Vibration." He received the degree of bachelor of applied science from the University of Toronto in 1929 and in that year became assistant engineer in the operating department of the Hydro-Electric Power Commission of Ontario with headquarters in Hamilton. He was made assistant testing engineer of the Commission's laboratories at Toronto in 1931 and later became testing engineer.

W. H. Huggins (Enrolled Student) Oregon State College, Corvallis, Oreg., has received honorable mention in the 1941 AIEE national prize award for Branch paper for his paper, "Design of the Low-Frequency Characteristics of Video Amplifiers." He received the degree of bachelor of arts from Oregon State College in 1941. He was chairman of the Oregon State College Branch AIEE, 1940–41, is a student member of the Institute of Radio Engineers, and is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu. He was awarded the 1940 AIEE national prize award for Branch paper (*EE, July '41, p. 353*).

A. M. McQuarrie (A'41) aircraft instrument engineering department, Canadian General Electric Company, Ltd., Peterboro, Ont., and co-author with H. G. Mah (A'41) and C. R. Hoar of the paper, "The Predetermination of the Regulation of Salient-Pole Alternators," has received the 1941 AIEE District 10 prize for Branch paper. He was born at Edson, Alberta, on August 16, 1914, and received the degree of bachelor of science in electrical engineering in 1940 from the University of Alberta. He joined the Canadian General Electric Company, Ltd., in 1941 as a test student.

V. Petrucelly, Jr. (Enrolled Student) has received honorable mention in the 1941 AIEE District 3 prize award for Branch paper for his paper, "An Automatic Intercommunicating System." In 1933 he was employed by the New York (N. Y.) Telephone Company in the commercial department and in 1936 was transferred to the plant department. During this time he attended night school at Cooper Union and was graduated from that institution with the degree of bachelor of electrical engineering in 1942. He is doing graduate work at present in cathode-ray oscillography at Brooklyn Polytechnic Institute.

H. G. Mah (A'41) engineering department, Burlec, Ltd., Toronto, Ont., and co-author with A. M. McQuarrie (A'41) and C. H. Hoar of the paper, "The Predetermination of the Regulation of Salient-Pole Alternators," has been awarded the 1941 AIEE District 10 prize for Branch paper. He was born at Cranbrook, B. C., on July 18, 1917, and was graduated from the University of Alberta with the degree of bachelor of science in electrical engineering. In 1940 he was employed by the Canadian Car and Foundry, Ltd., Fort William, Ont., and in 1941 he joined the Burlec company.

H. L. Olesen (M'27) assistant general sales manager, Weston Electrical Instrument Corporation, Newark, N. J., has been appointed to serve on the newly formed combat instruments industry advisory committee of the division of industry operations, War Production Board. **H. P. Sparkes** (A'21, M'25) sales manager, meter division, Westinghouse Electric and Manufacturing Company, Newark, N. J., and **D. J. Angus** (A'09, M'34) president, Esterline-Angus Company, Indianapolis, Ind., also have been appointed members of the committee.

D. R. Shoults (A'35) industrial engineering department, General Electric Company, Schenectady, N. Y., has been appointed engineer in the aviation division of that company's industrial department. He was born on June 23, 1903, at Storms, Ohio, and received the degree of bachelor of science from the University of Idaho in 1925. In that year he entered the test course of the General Electric Company and was engaged in test work until 1929 when he joined the industrial engineering department.

A. J. Dolan (A'42) electrical engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received the 1941 AIEE District 3 prize for Branch paper for his paper, "The Design and Construction of a Vacuum-Tube Voltmeter for Educational Use." He was born at Richmond Hill, N. Y., on May 17, 1918, and received the degree of bachelor of electrical engineering in 1941. In that year he joined the Westinghouse Electric and Manufacturing Company. He is also a member of Eta Kappa Nu.

C. L. Dudley (A'23, M'29) division superintendent, electric distribution department, Public Service Electric and Gas Company, Camden, N. J., has been appointed division superintendent, Essex division. He was first employed by that company as a cadet engineer in 1920. In 1922 he became field engineer in the distribution department; and in 1926 he was transferred to the office of the distribution engineer; and during 1927–28, he was acting district superintendent in charge of distribution.

F. H. Slaymaker (A'42) engineer, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., has received the 1941 AIEE District 6 prize for Branch paper for his paper, "Frequency Response and Efficiency Measurements of a Loud-Speaker." He was born at Lincoln, Nebr. on April 22, 1914, and was graduated from the University of Nebraska in 1941 with the degree of bachelor of science in electrical engineering. He has been with the Stromberg-Carlson company since 1941.

L. K. Davis (Enrolled Student) test engineer, General Electric Company, Schenectady, N. Y., and co-author with B. W. Pike (Enrolled Student) of the paper, "Localized Annealing of Rock-Bit Bodies by Sixty-Cycle Induction Heating," has received the 1941 AIEE District 7 prize for Branch paper. He was born on November 25, 1920, and received the degree of bachelor of science in electrical engineering from Rice Institute in 1942. He recently joined the General Electric Company.

W. C. Brown (A'42) student engineer, General Electric Company, Erie, Pa., has received honorable mention in the 1941 AIEE national prize award for Branch paper for his paper, "The Application of the Amplidyne as a Voltage Regulator." He was graduated in 1941 with the degree of bachelor of science in electrical engineering from the University of Colorado. He has been with the General Electric Company since 1941.

C. G. Smith (A'37) assistant engineer, Pacific Gas and Electric Company, San Francisco, Calif., has joined the switchgear engineering section of the General Electric Company, Philadelphia, Pa. He had been with the Pacific Gas and Electric Company since 1936.

C. L. Proctor (A'08) president and general manager, Toledo (Ohio) Edison Company recently was named salvage co-ordinator for Toledo, Ohio, at a meeting of War Production Board representatives with the local Chamber of Commerce.

L. C. Reed (A'38) manufacturers agent, New Orleans, La., has been awarded "a golden anniversary 50-year certificate" by the Electrical Association of New Orleans in recognition of his pioneering work in the electrical industry.

A. C. Streamer (A'10, M'41) vice-president, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been elected a vice-president of the National Electrical Manufacturers Association.

C. A. Hahn (M'22) in charge of engineering for the H. J. Heinz Company, Pittsburgh, Pa., is on leave of absence serving as an administrative consultant in Washington, D. C.

Richard Cutts, Jr. (A'29) meter specialist, General Electric Company, Boston, Mass., has been transferred to the meter division of the company's central-station department at West Lynn, Mass.

R. E. Walker (A'41) powerhouse operator, Powerdale Plant, Pacific Power and Light Company, Hood River, Oreg., has become principal radio electrician with the Civil Aeronautics Administration, Nome, Alaska.

S. B. Way (A'03, F'38) president, Wisconsin Electric Power Company, Milwaukee, Wis., has been awarded an honorary degree of doctor of science by Drexel Institute of Technology.

J. L. Kilpatrick (A'09) retired president of the New York Telephone Company, New York, N. Y., has also received an honorary degree of doctor of science from Drexel Institute of Technology.

F. E. Ricketts (A'16) vice-president, Consolidated Gas Electric Light and Power Company of Baltimore (Md.) recently was awarded an honorary degree of doctor of engineering by the University of Maryland.

J. H. Foote (A'18, F'32) supervising engineer, Commonwealth and Southern Corporation, Jackson, Mich., has been elected a member of the executive committee of the American Society for Testing Materials.

W. P. Dobson (A'13, M'19) chief testing engineer, Hydro-Electric Power Commission of Ontario, Toronto, has been elected president of the Dominion Council of Professional Engineers.

OBITUARY

Rudolf Lorenz Weber (A'16, M'27) Stone and Webster Engineering Corporation, Boston, Mass., died on April 27, 1942. He was born on September 14, 1883, in New York, N. Y., and received the degree of mechanical engineer from Cornell University in 1905. After doing miscellaneous mechanical and electrical work from 1905 to 1908, he became associated with Robert P. Woods, consulting engineer, as electrical construction engineer and in this capacity worked on the construction of the Portales (N. Mex.) Irrigation Project as well as the powerhouse of the Roswell Gas and Electric Company and the Berrendo Irrigated Farms Project, both at Roswell, N. Mex. He became equipment and power engineer for the Wyandotte Construction Company in 1911 and in this position did design and construction work on the Kansas City, Clay County, and St. Joseph Railway. He was employed as resident engineer at the Saxon Falls Hydroelectric Project, Ironwood and Bessemer Railway and Light Company, Inwood, Mich., from 1912 to 1913, when he joined Ford, Bacon, and Davis as construction and designing engineer. In 1914 he was appointed electrical engineer, Board of Control, Kansas City (Mo.) Railways Company, and in 1916 he was made engineer of equipment and power. Since 1924 he had been an engineer in the electrical division, Stone and Webster Engineering Corporation. He played a large part in the design and construction of steam and hydroelectric power stations—throughout the United States and had become prominent for his work on transit facilities and electric railway problems. He served as chairman of the AIEE Kansas City Section, 1923–24. He was also a member of The American Society of Mechanical Engineers, the American Society of Naval Engineers, and the American Transit Association.

Chester Waters Larner (A'12) president, Larner Engineering Company, Philadelphia, Pa., died June 11, 1942. He was born at Elizabeth, N. J., on March 3, 1881, and in 1897 was graduated from Baltimore Polytechnic Institute. In 1897 he joined the Standard Oil Company, Baltimore, Md., and in 1900 he became instructor in mathematics at the University of Chicago (Ill.). He was a structural designer with the New Jersey Bridge Company from 1901 to 1902, when he became designer of hydraulic turbines for the I. P. Morris Company. In 1906 he was employed by the International Steam Pump Company as mechanical engineer and in 1907 he became hydraulic engineer in charge of the hydraulic turbine department for the Wellman-Seaver-Morgan Company, Cleveland, Ohio. He was president of the Larner-Johnson Valve and Engineering Company from 1918 to 1922, when he became president of the Larner Engineering Company. He played a large part in the design of hydraulic machinery for water power plants and with R. E. Johnson was the inventor of the Larner-Johnson valve. He was also a member of The American Society of Mechanical Engineers and the American Society of Civil Engineers.

John Egli (A'26, M'36) assistant superintendent, manufacturing department, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died on May 10, 1942. He was born at Basle, Switzerland, March 4, 1892, and was graduated from the Swiss Federal Polytechnic University. He joined Maffei and Company, Munich, Germany, as a tool maker in 1911 and in 1912 was employed by the Brown Boveri Company, Baden, Switzerland, to work on the erection of electric power plants. Following an interval of study at the Swiss Federal Polytechnic University, he returned to the Brown Boveri Company to do research on mercury-arc rectifiers, and in 1924 he was made erection engineer. In 1925 he became supervising field engineer with the American Brown Boveri Electric Corporation, Camden, N. J., and 1928 became manager of the service and erecting department. When that company was taken over by the Allis-Chalmers company in 1931, he became an assistant superintendent in charge of the manufacture of transformers and mercury-arc rectifiers for the latter organization.

Ralph Waldo Eaton (A'07, M'13) public service engineer, city of Providence, R. I., died on June 1, 1942. He was born on February 13, 1880, at Hill, N. H., and was graduated from Massachusetts Institute of Technology in 1903 with the degree of bachelor of science. In that year he was employed by the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., as engineering apprentice, in 1905 he was transferred to that company's Boston office, and in 1907 he joined the sales department. In 1913 he became electrical engineer with the Connecticut Company, New Haven, and in 1914 he joined the Shore Line Electric Railway Company, Norwich, Conn., as electrical superintendent. In 1918 he became public service engineer for the city of Providence and in this capacity later worked on traffic problems.

George Marshall Cole (A'02) retired manager of the New York State Electric and Gas Corporation, Plattsburg, N. Y., died

January 6, 1942. He was born December 31, 1862, at Brockville, Ont. After being in charge of road construction from 1885 to 1889, he went to Plattsburg, N. Y., and in 1890 established the Plattsburg Light, Heat, and Power Company and became its manager. In 1896 he founded the Plattsburg Traction Company of which he was manager for a number of years. He continued to manage the Plattsburg Light, Heat, and Power Company and in 1924 when it was taken over by the Associated Company, he remained as head of the local organization, which was later the northern division of the New York State Electric and Gas Corporation. He retired from the managership in 1934.

Clifford Steele Van Dyke (A'11) rate engineer, New York Power and Light Corporation, died on May 8, 1942. He was born at Greenville, Ohio, on January 24, 1876, and was graduated from Ohio State University in 1902. In 1903 he joined the testing department of the General Electric Company and in 1906 he was employed by the Schenectady (N. Y.) Illuminating Company. He became superintendent for the Mohawk Edison Company, Inc., in 1919, and in 1920 he joined the Adirondack Power and Light Corporation as superintendent in the operating department, later becoming engineer. In 1927 he was employed by the New York Power and Light Corporation as rate engineer.

W. R. Hewitt (A'94) president, Rider Hewitt Lumber Company, San Francisco, Calif., died on February 21, 1940. He was born on September 17, 1868, at San Francisco, Calif., and attended Columbia University. In 1894 he became chief of the San Francisco (Calif.) Department of Electricity, and in 1908 he joined the Charles R. McCormick Company, San Francisco, as supervisor. In 1920 he established a lumber business in New York, N. Y., working with the McCormick company. In 1926 he terminated his association with that company and continued his own business until his retirement in 1938.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on July 23, 1942, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Bollinger, H. M., general plant dial system supervisor, Chesapeake and Potomac Telephone Company, Washington, D. C.

Crump, L. L., vice-president and chief engineer, James R. Kearney Corporation, St. Louis, Mo.

Defandorf, R. M., senior physicist, National Bureau of Standards, Washington, D. C.

Smith, H. L., chief engineer, The Louis Allis Company, Milwaukee, Wis.

Sparkes, H. P., manager, meter division sales, Westinghouse Electric and Manufacturing Company, Newark, N. J.

Vinal, G. W., physicist, National Bureau of Standards, Washington, D. C.

Wyman, M. B., manager, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

7 to grade of Fellow

To Grade of Member

Beckwith, S., engineer-in-charge, a-c design, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

Blegen, G. C., associate superintendent, power operation, United States Engineer Office, Bonneville, Oreg.

Chapman, H. H., manager, Westinghouse Electric and Manufacturing Company, Minneapolis, Minn.

Cook, S. S., section engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Crampton, R. E., appraisal engineer, Gary Heat, Light, and Water Company, Gary, Ind.

Downie, E. G., laboratory electrical engineer, General Electric Company, Fort Wayne, Ind.

Dunlap, L. J., syndicate representative, Westinghouse Electric and Manufacturing Company, Chicago, Ill.

Endres, L. M., chief mechanica service division, manager, P.B.A., Washington, D. C.

Fritz, L. J., district plant engineer, Ohio Bell Telephone Company, Dayton, Ohio.

Harris, K., electrical engineer, Detroit Edison Company, Detroit, Mich.

Hathaway, C. M., chief engineer, Hathaway Instrument Company, Denver, Colo.

Irwin, E. M., manager, Waugh Laboratories, Pasadena, Calif.

ames, H. C., chief engineer and general manager, North Loup River Public Power and Irrigation District, Arcadia, Nebr.

Kennedy, R. M., major, United States Army, Post Signal Officer, Fort Sam Houston, Tex.

Lewis, J. P., division engineer, Connecticut Power Company, Stamford, Conn.

McEachron, K. B., Jr., supervisor of advanced course, General Electric Company, Schenectady, N. Y.

Miner, R. W., Ohio Bell Telephone Company, Columbus, Ohio.

Nebbia, A. M., division power representative, Public Service Electric and Gas Company, Hackensack, N. J.

Peterson, E. F., head of electrical engineering department, University of Santa Clara, Santa Clara, Calif.

Plant, E. C., assistant engineer, Public Service Electric and Gas Company, Newark, N. J.

Ricker, E. A., assistant engineer, Hydroelectric Power Commission of Ontario, Toronto, Ont.

Ross, M. D., section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Sawle, R. T., design engineer, English Electric Company of Canada, Ltd., St. Catharines, Ontario, Canada.

Snow, L. D., supervisor of relays and voltage regulation, Puget Sound Power and Light Company, Seattle, Wash.

Ward, R. D., laboratory technician, Ward Leonard Electric Company, Mt. Vernon, N. Y.

25 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before August 31, 1942, or October 31, 1942, if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Miske, F., Eastman Kodak Company, Rochester, N. Y.

Sanderson, F. C., 6 Parson's Lane, Rochester, N. Y.

2. Middle Eastern

Berenhauser, C., Jr., Electrical Engineer, 2422 Euclid Avenue, Cleveland, Ohio.

Daily, C. F. (Associate re-election), American Telephone and Telegraph Company, Cincinnati, Ohio.

Dunn, J. A., Island Creek Coal Company, Holden, West Virginia.

Goolsby, G. N., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Kruger, S., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Locke, P. S., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Madsen, H. C. (Associate re-election), Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.

Mecklenborg, R. H., Jr., Automatic Temperature Control Company, Inc., Philadelphia, Pa.

Mentzer, J. R., Westinghouse Electric and Manufacturing Company, Baltimore, Md.

Myers, H. G. (Associate re-election), Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.

Peterson, A. V., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Roth, J. A., General Electric Company, Erie, Pa.

3. New York City

Blomsen, J. H., Cole Electric Products Company, Long Island City, N. Y.

Caldwell, O. H. (Member re-election), Caldwell-Clements, Inc., New York, New York.

Heins, H. H., Westinghouse Electric and Manufacturing Company, New York, N. Y.

Isaacs, M., Corps of Engineers, War Department, New York, N. Y.

Jacobus, R. F. (Member re-election), Engineer-Architect, New York, N. Y.

James, F. H., J. G. White Engineering Corporation New York, N. Y.

Kisbany, G. H. (Member), Consolidated Edison Company of New York, Inc., New York, N. Y.

La Manna, J. J., Chemical Construction Company, New York, N. Y.

Lewis, R. A., J. G. White Engineering Corporation, New York, N. Y.

Nicholson, G. C. J., Semet Solvay Engineering Company, New York, N. Y.

O'Riordan, P. A. (Member), Newfoundland Base Contractors, New York, N. Y.

Phelps, W. A. (Associate re-election), Bell Telephone Laboratories, Inc., New York, N. Y.

Schreuer, C. L., Gibbs and Cox, Incorporated, New York, N. Y.

4. Southern

Allen, G. W. (Member), United States Maritime Commission, New Orleans, La.

Bohner, C. W. (Member), Tennessee Valley Authority, Knoxville, Tenn.

Loboco, A. F., U. S. Maritime Commission, New Orleans, La.

McLemore, R. E., Tennessee Valley Authority, Pickwick Dam, Tenn.

Milburn, J. B. (Member), Electric Power Board, Chattanooga, Tenn.

St. Petery, L. B., United States Navy Department, Naval Air Station, Jacksonville, Fla.

Snyder, E. R. (Associate re-election), Tennessee Valley Authority, Knoxville, Tenn.

5. Great Lakes

Baker, M. A., General Electric Company, Fort Wayne, Ind.

Davis, D. W. (Associate re-election), Dean W. Davis and Company, Inc., Chicago, Ill.

Miller, C. G. (Associate re-election), Weston Electrical Instrument Company, Chicago, Ill.

Scheer, A., Sanderson and Porter, Joliet, Ill.

Sullivan, R. S., Indianapolis Power and Light Company, Indianapolis, Ind.

Weigel, F. W., Jr., E. I. du Pont Company, Charleston, Ind.

6. North Central

Marcum, T. E. (Associate re-election), Farm Credit Building, Omaha, Nebraska.

. South West

Eynon, A. W., U. S. Engineer Department, War Department, Tulsa, Oklahoma.

Fischer, D. A., Washington University, St. Louis, Mo.

Hilbert, E. E. (Associate re-election), Wagner Electric Corp., St. Louis, Mo.

Laughlin, L. W., Missouri Electric Power Company, Springfield, Mo.

Ratliff, K., Lower Colorado River Authority, Austin, Texas.

8. Pacific

Beebe, L. H. (Associate re-election), Southern California Edison Company, Ltd., Alhambra, Calif.

Haist, C. T., Jr., Boeing School of Aeronautics, Oakland, Calif.

Knapp, A. A., Elevator Maintenance Company, Ltd., Los Angeles, California.

Martin, F. G. (Associate re-election), Leeds, Hill, Barnard and Jewett, Los Angeles, Calif.

9. North West

Trowbridge, H. M., Westinghouse Electric and Manufacturing Company, Portland, Oregon.

10. Canada

Dillon, E. A., Canadian General Electric Company, Ltd., Peterboro, Ont.

Hardwick, A. P., Canadian General Electric Company, Peterborough, Ont.

Shearer, C. W., 957 Pelissier St., Windsor, Ont.

Total United States and Canada, 54

Elsewhere

Christie, J., A. Reyrolle and Company, Ltd., Hebburn-on-Tyne, England.

Wadeson, H. L. (Member), City of York Electricity Department, York, England.

Total, elsewhere, 2

OF CURRENT INTEREST

Army Specialist Corps Provides Means of Securing Technical Men for Services

Pointing out the necessity for priorities in brain power as well as in war materials, Brigadier General William O. Hotchkiss, deputy director, Army Specialist Corps, spoke at the annual meeting of the Society for the Promotion of Engineering Education on June 27, 1942, at New York, N. Y., on the formation and function of the Army Specialist Corps. The text of his address follows:

Recently I heard an experienced Army officer state emphatically that our most valuable asset is man power. I agreed with him heartily and added that that part of our man power with highly trained brain power was the most precious of all. We have read frequently of "bottlenecks" in the supply of steel plates for ships, or of engines for airplanes, or of tanks and guns. We have rarely seen in print the real bottleneck, which was that there were not enough men with the proper quantity and quality of brain power working on the problem in time. Every instance of "too little and too late" in ships, in supplies, and in munitions can be stated in terms of too little and too late application of trained brains to the problem.

For many lines of activity necessary for war purposes, there are not in existence a sufficient number of properly trained and skilled individuals. We have priorities on most kinds of materials, but we have not yet heard of any really adequate plan for priorities for our trained brain power. We have not yet developed a workable scheme to stop this waste. The matter is complex and involved, but nevertheless we must stop, in every way we can, the waste of the most precious part of our most valuable asset—trained man power. I know of no more effective way to aid our enemies, the Germans and the Japanese, than to permit in any way such waste. The man who sees it and does not strive to prevent it is guilty of some degree of "contributory treason" whether that be recognized as a crime or not.

In the conduct of war there is a wide diversity of occupations as there is in civil life, plus a wide range of duties that are not present in civil life. All these activities have a single aim and objective—the successful engagement of the enemy in combat. Everything is pointed toward the day when we go into the fight and win. To accomplish this objective all the preparatory duties must be well done. But no matter how perfectly the preparatory duties are done, the battle will not assuredly be won unless the officers in command can operate our troops better than the enemy officers operate theirs, other things being equal. Obviously the highest professional military skill is necessary for this. Someone has said that a good general is as valuable as an extra army. I think I should state it by paraphrasing the familiar old definition of an engineer, a good general is one who can do with one division the things an ordinary general can do with two.

One of the serious bottlenecks in this war is our supply of officers with professional military training and experience. We cannot afford to waste a single one on duties of any other nature. Always in peacetime we have maintained an army of relatively insignificant numbers. When war comes upon us it is not only a scramble to build the ships and planes and tanks and guns needed, it is a scramble to give anything like adequate professional military training to the great numbers of new officers required by the rapid expansion of the army. To waste this particularly valuable trained skill in any way is again in some degree contributory treason. There is no more effective way to help our enemies.

The transition from an army of 150,000 officers and men, which we had just a few years ago, to an army numbered in millions is really a catastrophe. It upsets everything both in personal lives and in business affairs. In a modern war few persons escape its effects. War is no longer the affair of armies; it is the affair of the whole populations of nations. Every man, woman, and child; every pound of steel, aluminum, and tin is a factor in this transition to total war and is affected by it. Every energy, every material, every mental resource we have must be used with the greatest possible speed and with the utmost practical efficiency if we are to be sure of winning this war.

ADJUNCTS TO MILITARY ACTIVITY

The highest function of a military officer is the effective use of his knowledge of strategy and the use of troops and equipment in contact with the enemy. There are multitudinous other functions which are vital adjuncts to these professional military functions. These adjunct functions, in many instances, can be performed satisfactorily by men who have gained the proper experience in their civil occupations. An army is like a great city. Its men must be housed and clothed. They must be fed and provided with necessary utilities—heat, water, light—and sanitary and hospital facilities. They require huge transportation facilities that must operate without fail under difficult and dangerous conditions. They require innumerable repair-shop units to keep their equipment in good operating condition. Roads and railroads must be built and bridges repaired or erected with great speed. All the vast quantities of supplies of clothing, food, shelter, vehicles, arms, tanks, planes, and munitions, must be contracted for, received and warehoused, paid for, shipped by rail, truck, airplane and ship, and shipped again from the unloading port by rail, truck, or airplane. The Army must be paid. A vast accounting job must be performed.

These adjunct duties are very closely parallel to the duties that must be performed in civil life. They can be performed by men who are not professional military men. Capable engineers and businessmen of many different kinds can be used to carry on much of this work, *but they must do it as officers under military command and with military responsibility, not as civilian employees who can quit the job whenever they desire.*

SPECIALIST CORPS FORMED

With such considerations in mind, General George C. Marshall, Chief of Staff, suggested to the Secretary of War the establishment of the Army Specialist Corps. One of the chief objectives was to enable our Army to make the most efficient use possible of the professional military training and talent available.

An erroneous impression has gained credence that only men who are beyond military age, or who are physically disqualified for military service will be appointed as officers in the Army Specialist Corps. Such is not the case. This is only one of the purposes of the establishment of the corps. A more important purpose is to secure officers who, though they lack the experience and training to command troops, can perform vitally important noncombatant military services along the lines of their civilian business and technical experience. It is very likely that thousands of Army Specialist Corps officers will serve with active units of the fighting forces in the air and on the ground. They can aid in transporting supplies and munitions. They can aid in operating the new technical equipment for air operations. They can carry on business and financial duties. They will help conduct the multifarious business of feeding, clothing, housing, equipping, and supplying the armed forces. They will aid in repairing damaged equipment and in many activities that will use fully the knowledge of engineering science, business, and financial matters they acquired as civilians. Many of these men will be of military age and most of them serving with combat units must be as physically fit as troop officers.

In addition to officers of military age and physical fitness, the Army Specialist Corps will appoint many officers from the group of overage and physically disqualified men. Men who for these reasons cannot

perform arduous work can be used for work similar in physical requirements to what they are now doing as civilians. In these cases the age and physical condition demanded will be only that necessary for the less arduous work they will be called on to do. In the selection of such officers, emphasis will be placed on their having the mental ability necessary for the job rather than on their physical condition.

DIVERSITY OF SERVICES

Quite naturally the greatest use for Army Specialist Corps officers is likely to be in the Services of Supply. This is a great procurement, transportation, and technical group of activities in which men qualified by civilian experience can most quickly and readily be put to work. Procurement objectives for many of the services have already been authorized, under which the definite requisitions for the appointment of Army Specialist Corps officers are now being prepared. As an illustration of the diversity of occupations to be served, the following partial list is given:

Transportation Division	Statistical Service
Corps of Engineers	Special Service
Signal Corps	General Depots Division
Quartermaster Corps	Provost Marshal General
Chemical Warfare Service	Judge Advocate General
Ordnance Department	Public Relations
Post Exchange Services	Military Intelligence

In addition to serving the organizations in the Services of Supply, Army Specialist Corps officers will be of use in the Ground Forces and in the Air Forces. They can serve as special service officers, supply officers, executive officers, engineer officers, research officers, statisticians, quartermaster officers, personnel officers, ordnance officers, public relations officers, communication officers, post exchange officers, finance and budget officers, and in many other fields. Many technical positions in motorized and air units can be filled by Army Specialist Corps appointees.

PURPOSES

Out of the preceding statements it may be well to summarize the main purposes of the Army Specialist Corps. One of the principal functions is to find, appoint, and assign to the requisitioning branch, men properly qualified by civilian experience to perform noncombatant military duties that would otherwise have to be performed by professional military officers of the Army of the United States. A second principal function is to help in the more complete use of man power, by using the services of men disqualified for arduous military duty by reason of age or partial physical disability. Many of these disqualified men are daily performing in their civil occupations the same kind of duty that the Army needs. In appointing such officers the physical qualification required is that they can do the job for which they are intended. Brains and experience are emphasized, and physical vigor is required only sufficient for the performance of the duties.

QUALIFICATIONS

The kind of men wanted for officers for the Army Specialist Corps is obvious. Men distinctly of officer quality are needed. They must be men of unquestioned loyalty, and integrity, of education sufficient for the job, of good teamwork capacity. They must have had experience sufficient to enable them to handle the particular job they are appointed to fill. For service in continental United States, only commissioned officers will at present be appointed. For service overseas, both commissioned and noncommissioned officers will be appointed.

Candidates for officers in the Army Specialist Corps will be sought widely throughout the nation. The Adjutant General's office and the Army Specialist Corps are co-operating in establishing offices in many principal cities to secure officers for both the Army of the United States and this corps. Corps area headquarters of the Army Specialist Corps will be in close co-operation and co-ordination with these offices. These offices will have lists of job specifications for the kind of positions to be filled. Through informed local sources they will seek men with the proper qualifications who are willing to offer their services to the United States. These procurement offices will be staffed jointly by officers of the Army of the United States and the Army Specialist Corps. It is believed that through these offices men of the finest quality can be brought into the service.

In addition to the men secured by these offices, the corps has access to the questionnaires (applications) now filed in the Adjutant General's Office, the Civil Service Commission, in the National Roster of Scientific and Specialized Personnel (see *EE, Aug. '41, p. 413–14*), and many other sources. When these fail to provide a sufficient number of properly qualified officers, the Army Specialist Corps is authorized to train men to fill the needs.

It is in this last group that it will be particularly valuable to have the complete co-operation of the engineering colleges in the United States. The Army and the Navy have jointly asked that graduates in electrical engineering during the last ten years be counted. They have failed to find in that group a sufficient number of men to train in the ultrahigh-frequency courses which they and the colleges are giving. Apparently it is going to be necessary to lower the sights to secure the numbers that must be trained. In all probability, it will be necessary to ask colleges to look through their records and circularize *all* engineering graduates of the last ten years, and also the students who dropped out before completing their work, men who completed only enough of their courses to have a background of physics and mathematics sufficient to warrant their being given refresher courses followed by the special courses needed to supply the current demand. Plans are now being formulated to ask the co-operation of colleges in this important project.

I want to emphasize here that many engineers under 30 years of age who are in Selective Service Class IV-F will be urgently needed for the Army Specialist Corps. Present plans are that such of these men as are selected for training will be commissioned as officers, some in the Army of the United States and others in the Army Specialist Corps. They will then be assigned for training to the various engineering schools and to the schools maintained by the Signal Corps in accordance with their qualifications and the needs of the service. It is hoped that the organization and management of the courses may be handled by the United States Office of Education under the National Advisory Committee for Engineering, Science, and Management Defense Training as their courses now are

Progress in Induction Motors Demonstrated

An induction motor rated 15 horsepower, made by the General Electric Company, Schenectady, N. Y., nearly 40 years ago, is compared with one of the company's 1942 models, rated 25 horsepower. M.H Wells (A'12) (right) designing engineer, General Electric induction-motor-engineering department, demonstrates the changes to W. J. Foster (F'16) (left), retired General Electric engineer, and C. A. Adams (F'13) (center), consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.

being given. In this way the existing facilities will be used most efficiently and duplication of teaching personnel, equipment, and expense eliminated.

Men eligible for appointment in the Army Specialist Corps are limited by a recent order of the Secretary of War. This provides that officers may not be commissioned in the corps who are:

a. In the 20–30 age group unless in class IV-F, "permanently physically disqualified for general military service"

b. In the 30–45 age group if in class I-A of the Selective Service

c. Deferred from induction for occupational reasons unless the Selective Service agrees that they may be taken into the Army Specialist Corps

Exceptions may be made in cases where the candidate has qualifications specially needed. In this connection it is well to remember that regulations and orders may be altered from time to time as conditions require. It is not improbable that, for the urgent needs of the Signal Corps, restriction *a* in the preceding paragraph may have to be modified to make men of the 20–30 age group in Selective Service classes I-B and III-A eligible for appointment in the Corps.

The Army Specialist Corps does not compete with the Selective Service. Men deferred for occupational reasons are not eligible. It is just as necessary to have these men producing war materials as it is to have men in the combat units to use them. Officers appointed to the corps are not thereby taken out of the jurisdiction of the Selective Service according to law. They may be recalled by their draft boards and inducted. But, of course, it is unlikely that corps officers serving overseas with troops will be brought home for induction. Overseas corps officers should be credited to the quota of their draft boards the same as men in the Army. While this is not now possible, it may become so as the needs become more apparent. Furthermore, since no Army Specialist Corps officers will be appointed from class I-A, it is improbable that many such officers will be called by their draft boards.

PROCEDURE FOR APPOINTMENT

As a matter of interest and information, the procedure necessary for appointment of officers in the Army Specialist Corps is set down here in chronological order. It is practically the same as for officers in the Army of the United States.

1. The Arm or Service needing Army Specialist Corps officers files an approved "procurement objective," which is its estimate of the total number of officers that it needs to have appointed

2. Under this it files requisitions stating the kinds of jobs to be done, the various ranks desired, when the officers will be needed, and where and to whom they are to report

3. Requisitions are distributed to the joint procurement offices throughout the United States, and search is also made in the files of the Adjutant General's Office and elsewhere for qualified men

4. Questionnaires (Form 0850) that have been filed with the Army Specialist Corps by applicants are studied, and compared, and records of suitable candidates are submitted to the requisitioning agency for their final approval, after personal interviews with the candidates if the agency so wishes

5. After this selection, the files are sent to the War Department Personnel Board which acts for the Secretary of War in approval or disapproval of the appointment

6. On return of the files of approved candidates, the files are sent to the Adjutant General's Office for issuance of the appointment, for securing the oath of office, and for issuance of Orders as to when and where the appointee is to report

7. Appointment of officers of the rank of major and above must go through a procedure in addition to those listed in item 6. After approval by the War Department Personnel Board, these officers' names must go to the Secretary of War and to the President who must nominate them to the Senate for its approval, which must be forthcoming before the commission and orders can be issued

The Army Specialist Corps will not maintain any operating force other than its headquarters and field procurement staff. All other officers appointed will be assigned immediately to the Arm or Service that requisitioned them. Thereafter they will be under the orders of that branch. Judging from the inquiries received, there is a general misconception of this matter. Many persons seem to think that the Army Specialist Corps will operate groups of specialists under its own command to serve the armed forces in special technical and scientific fields. Such is not the case. All activities of Specialist Corps officers other than its own administrative staff will be directly under the command of the various branches of the Army to which they are assigned.

OPPORTUNITY FOR SERVICE

From the picture given of the functions of the Army Specialist Corps, it should be obvious that the corps will afford an opportunity for service to many fine, loyal, patriotic citizens who have hitherto been barred for various reasons. Some have obligations to dependents which could not be met if they volunteered. This corps will provide an opportunity for many such to receive a commission which will enable them to care for these obligations. Others denied commissions in the regular army by reason of age or disability will be usable by the corps. Many in all these groups will find in the corps a very welcome opportunity for them to render the service their patriotism is seeking. The corps will be composed of men of outstanding ability and character. Every man in it will be serving because of his patriotic desire to do his bit for the United States in its time of need.

Power Companies' Stocks to Be Used in New Extensions

The War Production Board has notified electrical utilities that it has worked out plans for using materials in excess stocks of utilities in making electric extensions to housing projects. Henceforth the WPB will not grant authority for the purchase of such material in the open market for use in extensions to housing projects. All such material must come from excess stocks now on hand. These measures were taken because of the shortage of critical materials, especially copper.

As a part of this plan, the WPB power branch has received from electrical utilities reports on their excess stocks of wire and other materials. It is preparing a catalogue of such stocks—copper wire, distribution transformers, and meters—which will be furnished to all electrical utilities.

When a utility wishes to make an extension of more than 250 feet it must make application to the WPB, as Order P-46 requires WPB approval for extensions in excess of 250 feet. If the WPB approves the application, the utility will be authorized to use materials from its own stock or to acquire them from another utility company.

In addition, a new WPB requirement stipulates that no new housing project be started prior to obtaining approval for extensions of utility services. These services include not only electric service, but also gas and water. Utilities are asked to prepare promptly their applications for extensions for new housing projects.

In order to reduce the quantity of critical materials used in making electric, gas, and water extensions to housing projects, the WPB power branch has reduced the allowable weights of materials and distances for such extensions. For example, only 30 pounds of copper wire may be used per dwelling unit instead of the previous 60, and the distribution transformer capacity per unit may be only 200 watts instead of 300.

The new standards apply to houses on which construction began after April 22, 1942.

New Construction Regulations to Conserve Materials

In a move to make all possible material and effort available for immediate war production, top officials of the War Production Board and the War and Navy Departments have established broad principles governing all wartime construction which will bring such building under more rigid conservation control. The program means that no new plants will be built unless they are absolutely essential and can meet seven newly established criteria. This applies not only to direct war plants but to all other construction, both publicly and privately financed.

One of the main reasons for the new policy is that all critical materials are needed for war production now, and no materials can be spared for building new facilities except when they are absolutely necessary. The policy means simply that in the light of existing shortages, it is necessary to put materials and effort into airplanes, ships, tanks, and guns now, rather than putting them into plants which would not produce fighting weapons until a much later date. In addition, it is necessary to make the fullest possible use of all existing plant facilities that can be used or can be converted to use.

The principles were outlined in a directive, effective immediately, signed by Donald M. Nelson, chairman of the War Production Board, William H. Harrison

(F'31), director of production, Henry L. Stimson, Secretary of War and Frank Knox, Secretary of the Navy.

The seven criteria that must be met before any project will be approved for construction follow:

1. It is essential for the war effort.
2. Postponement of construction would be detrimental to the war effort.
3. It is not practical to rent or convert existing facilities for the purpose.
4. The construction will not result in duplication or unnecessary expansion of existing plants or facilities now under construction or about to be constructed.
5. All possible economies have been made in the project, resulting in deletion of all non-essential items and parts.
6. The projects have been designed of the simplest type, just sufficient to meet the minimum requirements.
7. Sufficient labor, public utilities, transportation, raw materials, equipment, and the like are available to build and operate the plant. The manufactured product can be used at once or stored until needed.

BUREAU OF CONSTRUCTION MOVES

The bureau of construction, recently established to co-ordinate all construction functions of the War Production Board, has moved to New York and opened headquarters in the Empire State Building.

Except for a small office staff that remained in Washington for liaison work, the entire organization under William V. Kahler, chief of the bureau, is affected by the change. Thomas L. Peyton, assistant to the chief, is in charge of the Washington office.

Substitute Materials in Electric Lamps

Use of critical materials in the manufacture of electric lamps is being curtailed without curtailing the production of the lamps themselves, by an amendment to Limitation Order *L*-28 recently issued by the War Production Board. This is made possible through the use of substitutes that will not affect the efficiency of the lamps. The base, formerly made of solid brass, is being made of steel plated with brass. Lamp leads, formerly made of a 50-50 combination of nickel and copper, are being made of iron wire plated with nickel and copper. Filament supports, formerly made of nickel and molybdenum, are being made of iron wire plated with nickel. The filament itself will continue to be made of tungsten, since no satisfactory substitute has been found. The plating process will require only about a tenth as much of the critical metals as was used before. The substitution provisions of the order went into effect July 1.

Not only will there not be a curtailment in the production of lamps, but the amendment permits greater production than in 1940. During the three-month period beginning July 1, and for each three-month period thereafter, a manufacturer is permitted to produce bases for incandescent and fluorescent lamps at a rate of 125 per cent of his production in 1940. In addition, he may exceed even that rate of production in one three-month period if he will reduce his production during the succeeding three months accordingly.

The amendment also prohibits the manufacture of Christmas-tree, advertising, and decorative or display lights. The original order reduced such production by 50 per cent. The amendment eliminates such production entirely, effective June 1.

The substitute provisions will not apply until September 6, 1942, to orders placed by or for the Army, Navy, or United States Maritime Commission. It has been estimated that the order will result in monthly savings of the following critical material, based on 1940 consumption: 1,000,000 pounds of brass, 40,000 pounds of copper, and 30,000 pounds of nickel.

Engineer Corps Needs Maps

Maps and aerial photographs of all areas outside the continental United States are wanted by the United States Army Corps of Engineers. Individuals and companies possessing such maps or photographs have been requested to notify the nearest office of the Foreign Map section of the Corps of Engineers. Copies will be made and the originals returned to the owners, it was announced. The offices to be contacted are:

New York Unit, Room 820, 1270 Sixth Avenue, New York, N. Y., Circle 6-1484.

New Orleans Unit, Room 900-A, Maritime Building, New Orleans, La., Magnolia 4006.

San Francisco Unit, Room 546, 74 New Montgomery Street, San Francisco, Calif., Exbrook 2009.

Intelligence Branch, Office, Chief of Engineers, United States Army, Room 3168, New War Department Building, Washington, D. C., Republic 6700, extension 5234-6409.

FPC Loans Staff to WPB

Approximately half of the national-defense staff of the Federal Power Commission has been loaned to the Power Branch of the War Production Board for the duration of the war, according to recent announcement. The Power Branch will have jurisdiction over such wartime power matters as supply, requirements, and rationing. Full authority over plant protection is retained by the FPC, as are regulatory powers.

WPB Issues Booklet on Plant Efficiency. The division of information of the War Production Board has published a booklet called "Plant Efficiency—Ideas and Suggestions on Increasing Efficiency in Smaller Plants," designed primarily for smaller war plants or for plants which are just getting into war production and which might be able to increase production by a study of efficiency procedures. The booklet includes chapters on lighting; cutting down of accidents; adapting old machines to new jobs; maintenance and repair; longer life for cutting tools; getting the most out of machine tools; production lines geared for war; meeting government standards; training workers quickly; swing shifts; keeping track of orders, production, and materials; plant protection; pooling facilities; priorities; and getting into war work. Copies may be obtained upon request from regional and local offices of the WPB located in 120 cities; from local offices of the division of information, office for emergency management; or by writing to the division of information, office for emergency management, Washington, D. C.

OEM Functions Described in Booklet. A publication entitled "OEM Handbook," describing the functions and organization of the war agencies within the Office for Emergency Management, was issued recently. The 72-page booklet describes in detail the organization of the War Production Board, the Office of Price Administration, and the other constituent agencies of the OEM. Personnel is listed in most cases down to the branch level in each agency. Included are organization charts of the WPB and the Bureau of Industry Branches of the WPB Division of Industry Operations, as well as a chart showing the relationship of the various Federal war agencies. Copies of the booklet are available in room 1501, New Social Security Building, and from the Superintendent of Documents, Washington, D. C., as well as from OEM field offices.

Planning Board Issues Pamphlet on Cities. A 22-page pamphlet called "Better Cities" has recently been issued by the National Resources Planning Board, as the third in its series on postwar planning. The first two were "After Defense—What?" and "After the War—Full Employment." The pamphlet on city planning, prepared by Charles S. Ascher, consultant to the board and former executive director of the National Association of Housing Officials, points out that the end of the war will offer the people of the United States an opportunity to rebuild their cities and suggests some concepts which should underlie such a rebuilding program. Planning on a broad scale—"by the square mile, not the square block," study of new methods, and more effective co-ordination of public and private efforts are among the concepts emphasized.

INDUSTRY . . . . .

Coffin Award to San Diego Company. The San Diego (Calif.) Gas and Electric Company has been presented the Charles A. Coffin award for 1941 in recognition of the company's outstanding record of performance in contributing to the development of electric light and power for public and industrial purposes. Presentation of the gold medal was made at a recent meeting of the Edison Electric Institute. The

Magnetic Table for Grinding Machine

Production of turbine parts at the Westinghouse Electric and Manufacturing Company's new merchant marine works is speeded by use of a grinding machine with a magnetic table that holds parts in place without requiring adjustment of clamps and enables simultaneous finishing of several parts.

award also includes $1,000 for the employees' welfare organization. The Charles A. Coffin Foundation, which makes the award, was established by the General Electric Company in 1922 in honor of its founder and first president.

Arbitration Group Elects Wilson. Charles E. Wilson, president of the General Electric Company, Schenectady, N. Y., has recently been elected a member of the board of directors of the American Arbitration Association. The Association, a nonprofit organization with headquarters in New York, N. Y., provides voluntary arbitration facilities to industry, through a panel of arbitrators consisting of some 8,000 educators, professional men, and business men located in cities throughout the United States, Canada, and Central and South American countries.

LIBRARY

Orders Increasing for Photostat and Microfilm Copies

The photostatic and microfilm processes for reproducing documents are attracting steadily growing attention, and the experience of the Engineering Societies Library indicates that more and more members of the societies are making use of these processes. Orders for such copies are 25 per cent greater this year than last. Not only requests for single articles one or two pages long, but orders calling for hundreds of prints come in. Many establishments build up files of all articles relating to their work instead of collecting sets of periodicals. In this way much space is saved by the elimination of irrelevant material.

Both methods of copying have their advantages. Photostats resemble ordinary documents. They can be filed in the same way, in letter files or loose-leaf binders. Several can be spread out and consulted simultaneously. Other documents can be interfiled with them.

Microfilm copies are cheaper and when long articles or whole books are to be copied the saving is large. To use them, some sort of projection apparatus or reading machine is necessary. These machines are as yet not common office equipment. Good ones cost about what typewriters do. Film is not as easy to store and handle as photostats are.

Up to now, most members have seemed to prefer photostat copies, but the Library is ready at all times to supply either photostats or microfilms, as desired.

JOINT ACTIVITIES

Industrial Lighting Standard Issued. An important and timely contribution is represented in the new American Standard, "American Recommended Practice of Industrial Lighting," a report recently completed under the sponsorship of the Illuminating Engineering Society through the collaboration of a Sectional Committee organized under the rules and procedures of the American Standards Association. This new code supersedes and replaces an earlier work entitled "Code of Lighting: Factories, Mills, and Other Work Places," which was adopted August 18, 1930, as an American Standard. Text of the new code was published in the May 1942 issue of *Illuminating Engineering* and thus distributed throughout the membership of the Illuminating Engineering Society.

Standard for Dry Cells and Batteries. A new edition of the American Standard Specifications for Dry Cells and Batteries, C18-1941, has been issued by the American Standards Association. In addition to types of batteries covered in the last edition of this Standard, the new edition includes best standard practice in miniature cells and batteries for portable radios, radio sondes, and newer types of vacuum-tube hearing-aid devices. Recommendations for further development of hearing-aid batteries are included. Copies of the Standard may be obtained from ASA headquarters, 29 West 39th Street, New York, N. Y., at ten cents each. Among the members of the ASA Sectional Committee which prepared the new edition are:

G. W. Vinal (M'19), National Bureau of Standards, *chairman;* W. B. Kouwenhoven (F'34), Johns Hopkins University, AIEE representative and member at large; H. C. Koenig (M'30), Electrical Testing Laboratories, Association of Edison Illuminating Companies representative; H. M. Turner (M'20), Yale University, Institute of Radio Engineers representative; E. B. Wheeler (M'21), Bell Telephone Laboratories, ASA Telephone Group representative.

OTHER SOCIETIES

Industrial Research Institute Elects Officers

At the fourth annual meeting of the Industrial Research Institute held in Cleveland, Ohio, May 22–23, 1942, more than 50 industrial executives and research directors participated in round-table discussions on the adjustment of research programs and personnel to meet war conditions. The program also featured inspection visits to the new Thompson Aircraft Products Company plant at Euclid, Ohio, and the General Electric Institute, Nela Park.

New officers of the Industrial Research Institute for the ensuing year were announced as follows:

H. S. Benson, administrative engineer, research division, United Shoe Machinery Corporation, Beverly, Mass., *chairman* of the executive committee; W. R. Hainsworth, vice-president, Servel, Inc., New York, N. Y., *vice-chairman;* P. W. Pillsbury, president, Pillsbury Flour Mills Company, Minneapolis, Minn., and

Future Meetings of Other Societies

American Institute of Chemical Engineers. 35th annual meeting, November 16–18, 1942, Cincinnati, Ohio.

American Institute of Mining and Metallurgical Engineers. Regional meeting, October 12–17, 1942, Los Angeles, Calif.; joint meeting, coal division, AIME, and fuel division, ASME, October 1–2, 1942, St. Louis, Mo.

American Physical Society. 251st meeting, November 27–28, 1942, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, October 12–14, 1942, Rochester, N. Y.

American Society of Tool Engineers. Semiannual meeting, October 16–17, 1942, Springfield, Mass.

American Welding Society. 23d annual meeting, October 12–15, 1942, Detroit, Mich.

Association of Iron and Steel Engineers. Annual convention, September 22–24, 1942, Pittsburgh, Pa.

Illuminating Engineering Society. Annual convention, September 21–22, 1942, St. Louis, Mo.

National Safety Council. 31st national safety congress and exposition, October 6–8, 1942, Chicago, Ill.

Harold K. Work, manager of research and development, Jones and Laughlin Steel Corporation, Pittsburgh, Pa., members of the executive committee elected for three-year terms. Other members of the committee are: F. W. Blair, chemical director, Procter and Gamble Company, Ivorydale, Ohio; C. P. Haskins, president, Haskins Laboratories, New York, N. Y.; Maurice Holland (M'30) division of engineering and industrial research, National Research Council, New York, N. Y.; and R. C. Newton, vice-president, Swift and Company, Chicago, Ill.

ASTM Awards Medal; Elects Officers

At the 45th annual meeting of the American Society for Testing Materials held on June 24, 1942, at Atlantic City, N. J., the Charles B. Dudley Medal, established to commemorate the society's first president, was awarded jointly to F. C. Todd (A'27) assistant professor, mineral industries experiment station and A. W. Gauger, director mineral industries research, both of Pennsylvania State College, for their paper, "Studies on Measurement of Water Vapor in Gases," which was presented at the 1941 ASTM annual meeting. The award is given for a technical paper which is considered to be of outstanding merit and which constitutes a contribution of original research.

ASTM officers for 1942–43 as announced at the meeting are as follows:

President: H. J. Ball, professor of textile engineering, Lowell (Mass.) Textile Institute.

Vice-presidents: P. H. Bates, chief, clay and silicate products division, National Bureau of Standards, Washington, D. C.

Members of the executive committee: R. P. Anderson, secretary, division of refining, American Petroleum Institute, New York, N. Y.; M. H. Bigelow, director of technical service, Plaskon Company, Inc., Toledo, Ohio; J. H. Foote (A'18, F'32) supervising engineer, Commonwealth and Southern Corporation, Jackson, Mich.; Alexander Foster, Jr., vice-president, Warner Company, Philadelphia, Pa.; and L. H. Fry, railway engineer, Edgewater Steel Company, Pittsburgh, Pa.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers, publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Laplacian Transform Analysis

To the Editor:

I believe that the closing sentence in Millman's article in the April 1941 issue of *Electrical Engineering* ("Laplacian Transform Analysis of Circuits With Linear Lumped Parameters," by Jacob Millman, pages 197–205) cannot be substantiated when the circuit consists of a relatively small number of branches having lumped constants, such for example as his illustrative circuit of Figure 3. The classical method has far greater possibilities than this article indicates. In fact, I have found from a detailed study of a number of typical conditions involving second- and fourth-order equations that, on the average, *more* arithmetical computation is necessary when the transform method is used than when the classical method is used effectively. A number of my associates believe that this information is of considerable interest and warrants publication.

WALDO V. LYON
(Professor of electrical engineering, Massachusetts Institute of Technology, Cambridge)

Distribution Systems in Wartime

To the Editor:

J. A. Krug, chief of the power division of the War Production Board, in his address before the Institute on January 26, 1942 ("Mobilizing Kilowatts for War," *EE, Mar. '41, p. 126–31*), referred to the tremendous demands that would come on the utility systems this year and next for a maximum "all out" war effort. Most of our efforts in planning for power supply to meet the war load have been centered largely on the provision of adequate generating capacity, of transmission lines, and interconnections between systems. It is therefore very pertinent that the attention of the electrical engineers of the country now be directed to the effect of the war on distribution systems and in planning and providing such measures and facilities as will meet the increased demands upon such systems.

Because of the flexibility of our power-supply systems, from generators, transmission systems, substations, to distribution systems, and through the use of reserves and interconnections with neighboring utilities and with private industrial generating plants, much additional load can be carried with the present facilities for an "all out" war effort. However, with all facilities used to their maximum, in many areas the loads will be greater than present facilities can handle and rationing of power in these areas will become necessary.

The curtailment of sales promotion and restrictions in the sale of new appliances through diversion of these industries to the manufacture of war materials undoubtedly will help to relieve the utilities from making further extensions of their distribution systems except to supply war industries, national-defense housing projects, and other essential services.

The recent order of the War Production Board limiting the extensions to meet war loads, and limiting new services to the areas served from existing lines by utility systems, will help still further to relieve the loads on distribution systems.

Many distribution systems which have been well designed with adequate copper in primaries and secondaries and adequate feeder cable can carry additional energy loads without much additional investment other than the distribution transformers. It has been estimated that on some systems load factors can be increased so that as much as 40 per cent additional energy can be furnished over existing systems without much increase in peaks. Those systems, however, in which copper was skimped in the original design and which have been constructed more or less on a "shoestring" basis, will find themselves in great difficulty. The problem may be met on these by permitting higher voltage drops, that is, poorer regulation, by installing feeder voltage regulators where none are now used; or, as has been pointed out in one of the papers in the symposium on distribution systems in wartime (AIEE *Transactions*, volume 61, 1942, March section, pages 105–26), by installing boosters or shunt capacitors, or by reinforcing existing feeders, which of course will require more copper, a critical and vital war material at the present time.

These wartime loads through longer hours' use bring a tremendous increase in daily, monthly, and annual load factors. Some feeders now are operating with load factors higher than the system load factor. With higher load factors, diversity between feeders and loads is reduced and tends to disappear. As feeders and transformers have to carry these sustained loads, it becomes all the more important to keep a careful watch on cable and transformer loads and temperatures, especially in view of the difficulty of maintaining a suitable stock of spares or of getting replacements except in extreme emergencies such as breakdown or the burnout of equipment. We will have to take these chances, however, and run the risk of furnishing less reliable service in order to assure adequate power supply to all the war industries and essential uses.

Before the outbreak of the war in Europe, the British Government, in co-operation with the utilities, provided stocks of breakers and other switching equipment, transformers, and wire and cable at suitable points. Experience has demonstrated that these proved very useful in restoring service quickly after air raids. Our problem in the United States is somewhat different, however, as many of our systems are as large as the British Grid, are more extensive, and cover more territory. Then again, we may not be subjected to the same danger from air raids except along our east and west coasts.

After the invasion of Norway, Holland, Belgium, and France in the spring of 1940, it became apparent that emergency measures must be adopted to prepare the power systems of the United States to meet the

threat of war. On June 14, 1940, the President directed the Federal Power Commission to take the necessary steps to assure an adequate power supply to all points where most needed for national defense.

In carrying out this directive of the President, conferences were held with both public and privately owned utilities, with manufacturers of equipment—steam turbine generators, boilers, water wheels, water-wheel generators, oil circuit breakers, transformers, insulators, and distribution equipment, and plans developed for meeting the war loads and assuring power supply to vital national-defense industries and for protection of electric-utility properties.

As a result of these conferences, some utilities proceeded at once to order additional stocks of standard sizes of wire and cable, insulators and switching equipment, for use for extensions later on, but as replacements during the emergency. This material was ordered, in so far as possible, in standard sizes and voltages so that it could be made available to other systems.

In the President's directive, the Federal Power Commission was requested to maintain contacts with all vital national-defense industries to insure continuity of power supply, as well as adequate power supply for all defense needs. For those industries having their own generating plants this may involve interconnection with the central stations and their transmission systems; for those now connected with the utilities or purchasing all of their power supply, it may require reinforcing existing feeders, running a loop feeder into the customer's substation or a duplicate feeder to insure ample power supply and continuity of operation. The size of the load and the relative importance of the product in the war effort are the important factors in determining the lengths to which we should go in providing continuity of power supply to these industries.

In view of the fact that on many systems the available generating capacity and that now scheduled for installation this year and next will be insufficient to meet the war loads, the Commission, through its regional offices, has started a survey on each power system of the loads to be anticipated, power supply to different classes of consumers, and methods of reducing peaks and conserving energy, as well as of rationing power should that become necessary. This will also involve an analysis of the character of loads on each feeder and the preparation of a plan to be put into effect immediately for pulling switches on less essential loads should a breakdown of a generating unit or an entire generating station occur.

One phase of the Commission's work is the necessity of protecting existing equipment against all hostile acts. Several of the papers in the symposium emphasized the difficulty of securing new equipment for expansion or replacement. It is highly important, therefore, that existing equipment be protected against all hazards.

It has been found that most of the measures adopted prior to the entry of the United States into the War would also provide greater protection and reliability of service in peacetime. Protection during wartime, however, will require eternal vigilance during the emergency to prevent failures of equipment and to restore service as quickly as possible in the event of accidental failure.

As pointed out in Philip Sporn's paper, "Electric Power Distribution Systems in Wartime" (*Trans. '41, Mar. sec., p. 105–07*), it is inappropriate to discuss these protection measures in detail, but the Commission's staff has been and is now actively engaged in protective surveys and is carrying out joint inspections with the Army authorities having jurisdiction. This may appear to some of the utilities to be a duplication of the previous surveys made by members of the Commission staff. It must be remembered, however, that we are now actually at war and that additional protective measures will become necessary to meet the rapidly changing conditions in order to insure continuity of power supply and to maintain full war production.

THOMAS R. TATE (F'35)

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NEW BOOKS • • •

Fundamentals of Radio. By E. C. Jordan, P. H. Nelson, W. C. Osterbrock (M'41), F. H. Pumphrey (M'25), and L. C. Smeby; W. L. Everitt (F'36) editor. Prentice-Hall, Inc., New York, 1942. 400 pages, illustrations, etc., 6 by 9½ inches, trade price $5, discount for schools.

Designed as a text to meet the requirements of the wartime program to train technicians for the armed forces, for industry, and for radio broadcasting, this book aims to cover the field of basic radio communication. The material is presented with a minimum of mathematics, necessary elements of which are briefly reviewed in the opening chapter, and is planned to train those who must maintain and operate apparatus rather than design it. Direct and alternating current, vacuum-tube theory and applications, wire telephony, audio systems, and frequency-modulation transmission are among the topics discussed.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

These and thousands of other technical books may be borrowed from the library by mail by AIEE members.

All inquiries related to purchase of all books reviewed in these columns should be addressed to the publisher of the book in question.

Table of Natural Logarithms. Volume 4, Logarithms of the Decimal Numbers from 5.0000 to 10.0000. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York. Published by the National Bureau of Standards, 1941, Washington, D. C. 506 pages, tables, 11 by 8 inches, cloth, $2.

This last volume of a series of four contains the 16 decimal-place values of the natural logarithms of the decimal numbers from 5 to 10 at intervals of 0.0001. The three preceding volumes contained the 16 decimal-place values of the natural logarithms of the decimal numbers from 0 to 5 at intervals of 0.0001 and of the integers from 1 to 100,000.

Tin Solders: a Modern Study of the Properties of Tin Solders and Soldered Joints. (Research Monograph No. 1) By S. J. Nightingale. Second edition, revised by O. F. Hudson. British Non-Ferrous Metals Research Association, London, 1942. 117 pages, illustrations, etc., 10 by 6 inches, cloth, $2.75.

The results of further investigations, chiefly on the creep properties of solders and soldered joints, are incorporated in this edition. The first section of the book deals with the constitution of the tin solders; their structure; the mechanical properties of the solder alloys; the strength of soldered joints; creep properties of solder alloys and soldered joints; and alloying between the solder and the joint members. The second part discusses such practical considerations as fluxes, spacing, wiped joints, and the choice of a solder.

Tables of Physical and Chemical Constants and Some Mathematical Functions. By G. W. C. Kaye and T. H. Laby. 9th edition. Longmans, Green and Company, New York, London, Toronto, 1941. 191 pages, tables, 10 by 6½ inches, cloth, $5.

Aims to fill the need for an up-to-date collection of physical and chemical tables which will meet the usual needs in teaching and laboratory work. The new edition has been thoroughly revised and expanded.

United States Tennessee Valley Authority, The Chickamauga Project. (Technical Report No. 6) Tennessee Valley Authority, Treasurer's Office, Knoxville, Tenn., 1942. 451 pages, illustrations, etc., 9½ by 6 inches, cloth, $1.

Facts concerning the planning, design, construction, and initial operations of the Chickamauga project of the Tennessee Valley Authority are presented. Unusual and unprecedented features and methods are described in some detail, while common procedures and practices are briefly treated. Chapter bibliographies, a section on costs, and a statistical summary are included.

Physics for Engineers. By Sir A. Fleming. Chemical Publishing Company, Brooklyn, N. Y., 1942. 232 pages, illustrations, etc., 9 by 5½ inches, fabrikoid, $3.

Attempts to summarize current knowledge in the realm of physics with special reference to the requirements of practical engineers. The fundamental physical units, various aspects of energy, electricity, electronic emissions, radiation, optics, sound, and atomic transformations are discussed.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1942 Supplement to Electrical Engineering—Transactions Section

Modern Impulse Generators for Testing Lightning Arresters

THEODORE BROWNLEE
ASSOCIATE AIEE

NATURAL lightning is very destructive and so elusive that it cannot readily be used for testing. However, the behavior of materials or equipment which are subject to lightning may be studied with artificial lightning from the impulse generator. In impulse testing of insulation strength, it is necessary to control only the wave shape and magnitude of the impulse voltage. There are numerous papers[1-8] describing methods of producing and measuring impulse voltages, and other papers[1,2,8-9] show how to calculate the circuit constants required to produce such waves.

The complete testing of lightning arresters requires, in addition to means for obtaining voltage waves, facilities for the accurate control of both magnitude and wave shape of discharge current. A variety of these impulse current waves are needed to simulate service conditions reasonably. The newly revised AIEE Lightning Arrester Standards No. 28 include tests with 10x20-microsecond waves of 5,000, 10,000, and 20,000 amperes; 5x10-microsecond waves of 65,000 and 100,000 amperes; and 10,000, 15,000, and 20,000 ampere tests with a nominal wave steepness of 5,000 amperes per microsecond. Since the internal impedance of the arrester is a factor affecting the impulse current, the complete testing of various types and ratings of arresters requires impulse generators with considerable flexibility and facility for quick adjustment. This paper describes several impulse generators designed primarily for lightning-arrester testing, and which have proved over years of constant use to have the desirable features of safety, flexibility, reliability, and convenience.

The circuit constants necessary to produce various current waves cannot be calculated exactly, because the resistance of the arrester valve element is not constant but a function of the voltage or current. So far as the author is aware, the methods for determining such circuit constants have not been published although there have been described impulse generators[10,11] which are adapted for lightning-arrester testing with different current waves. Through long experience, methods of approximate calculation have been developed, chiefly by the use of curves, which enable circuit constants to be selected roughly with a minimum of cut-and-try procedure. These methods are general in character and are applicable to unidirectional or oscillatory waves, including, of course, those specified in the AIEE Standards.

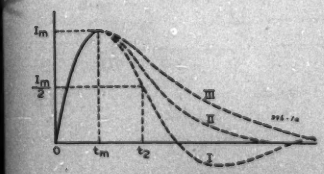

Figure 1a. Typical impulse-current waves

The time to crest for all three waves is designated by t_m, but t_2, as shown, represents the time to half value for wave I only

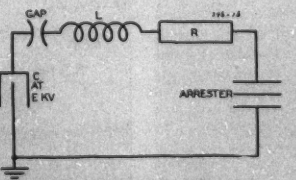

Figure 1b. Typical *RLC* impulse circuit

List of Symbols

The following symbols refer to the impulse-generator waves or circuit of Figure 1:

C = capacitance in microfarads
E = initial voltage on C in kilovolts
L = inductance in microhenrys
R = constant resistance in ohms
R_A = resistance of arrester*
R_T = total circuit resistance = $R + R_A$*
R_1 = critical resistance below which oscillations are produced
I_m = crest of current wave in kiloamperes
t_m = time in microseconds corresponding to I_m
t_2 = time in microseconds corresponding to $0.5I_m$ (on tail)
Δ = ratio of crest current for any half cycle to that of the preceding half cycle in an exponentially damped sine wave
E_m = crest of voltage wave produced by current wave through R_T

Typical Waves and Circuits

Figure 1a shows three current waves** and Figure 1b the customary circuit for producing such waves. The wave shapes I, II, and III are produced by circuits in which the total resistance is respectively

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*R_A and R_T are not constant but functions of voltage (or current) and time. Consequently R_A and R_T can only be represented completely as curves of instantaneous resistance plotted as a function of time. Such curves have a minimum at or a little after the maximum current.

**For time measurements in Figure 1a and throughout this paper, the actual zero is used. AIEE Standards No. 28 use the virtual zero which is the intersection on the time axis of a straight line projected through the 10 and 90 per cent points on the front of the wave. There is little practical difference, amounting to the order of only 1 per cent of the time to half value on the tail, for the waves here considered.

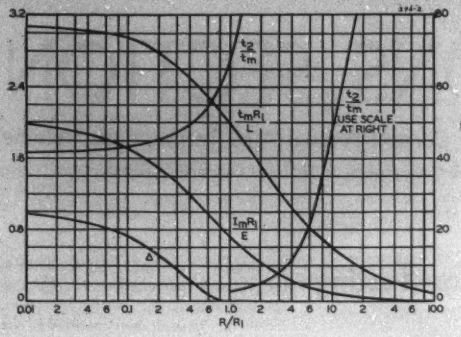

Figure 2. Effect of resistance on waves in *RLC* circuit

less than, equal to, or greater than the critical resistance. This total resistance R_T is composed of the constant resistance R and the nonlinear resistance R_A of the arrester. Valve-type arresters are designed to have a variable resistance R_A which is low at high currents but high at low currents, and R_A is the principal stumbling block to straightforward calculations of impulse circuits.

While both types of resistance may be present in any proportion, it will be shown how to compute the circuit constants when the resistance is predominantly linear or predominantly variable; from these, rough interpolations can be made for various combinations.

Before specific cases are considered, the principles of similarity and proportionality of circuit constants should be emphasized. Waves having similar shapes are those which can be represented by a single plot if either or both co-ordinate scales are multiplied by the necessary factors. In an *RLC* circuit as shown in Figure 1b the wave shape depends only upon $R_T/\sqrt{4L/C}$. If R_A is negligible, R_T is a constant and the above expression is a simple ratio of definite constants. However, if R_A is not negligible, R_T is really a function of time, as explained in the list of symbols. In this condition the expression is of little use; but with different waves of similar shape, the curves of R_T versus time also are similar, and any two corresponding values of R_T, such as those at maximum current, can be used for comparison purposes.

For current waves of similar shape, the circuit constants and wave specifications are so related that the following ratios are constant.

1. $t_m/\sqrt{LC}$
2. $t_2/\sqrt{LC}$
3. $E/I_m R_T$
4. E/E_m
5. $I_m t_2/CE$

It is possible to determine experimentally circuit constants to produce various wave shapes and by use of the above principles to calculate directly the constants required for other waves, similar in shape, but of different magnitudes or durations. Since the resistance may be a function of the current or voltage, the wave shape depends upon the voltage of the impulse generator as well as upon its other constants.

Calculations When Arrester Resistance Is Low in Comparison With Total Circuit Resistance

For the cases where the arrester resistance can be neglected (or lumped with the circuit resistance) the current for any particular circuit can be found easily from the well-known equations:

$$I=(E/\omega L)\epsilon^{-\alpha t}\sin\omega t \quad \text{where } R<R_1 \qquad (1)$$

$$=\frac{Et\epsilon^{-\alpha t}}{L} \quad \text{where } R=R_1 \qquad (2)$$

$$=\frac{E}{L}\,\frac{\epsilon^{-mt}-\epsilon^{-nt}}{n-m} \quad \text{where } R>R_1 \qquad (3)$$

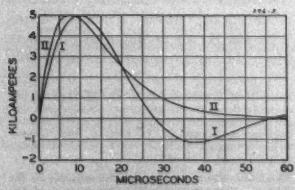

Figure 3. Impulse-current waves calculated by curves of Figure 2

		Wave I	Wave II
Given	C	1	1
	t_m	10	—
	t_2	20	20
	I_m	5	5
	Shape	—	Critically damped
Found From Curves	E	68.5	101
	L	64.0	55.5
	R	6.88	14.9

Wave I. $I=9.5\epsilon^{-0.054t}\sin 0.113t$

Wave II. $I=1.18t\epsilon^{-0.134t}$

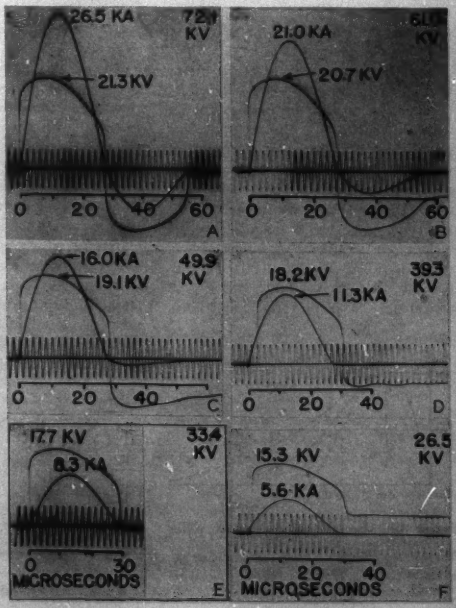

Figure 4. Current and voltage oscillograms on lightning-arrester element in *RLC* circuit of Figure 1b

$C=4.41$; $L=15.4$; $R=0.142$. The same arrester element was used for all six waves with the wave shape determined only by E which is listed in upper right-hand corner of each oscillogram

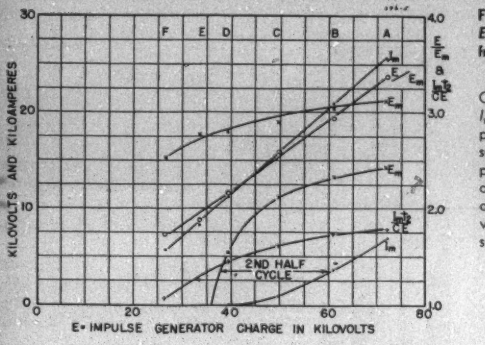

Figure 5. Curves of E_m and I_m taken from oscillograms of Figure 4

Curves of E/E_m and $I_m t_2/CE$ are computed from these results, but are applicable for any other combinations of circuit constants which can produce similar wave shapes

$$a=\frac{R}{2L};\quad \omega=\sqrt{\frac{1}{LC}-a^2};\quad m=\frac{R-\sqrt{R^2-R_1^2}}{2L};\quad n=\frac{R+\sqrt{R^2-R_1^2}}{2L}$$

Equation 1 defines an oscillatory wave such as wave I in Figure 1a, while equations 2 and 3 are for the nonoscillatory waves II and III, respectively.

Equations 1, 2, and 3 are transcendental and it is not possible to calculate directly the equation for a specified impulse such as a 5,000-ampere 10x20-microsecond wave. It is best to assume various circuit constants and plot curves which then can be used directly. It is found that for the RLC circuits the shape of the current wave depends only upon the ratio R/R_1 and this ratio is the most convenient parameter for abscissa of the curves. Figure 2 shows a set of such curves with ratios of R/R_1 from 0.01 to 100. The left-hand side of Figure 2 represents oscillatory conditions and the right-hand side nonoscillatory conditions. For a 5x10- or 10x20-microsecond wave, $t_2/t_m=2$, and it is found that such a relation holds only for oscillatory waves for which $R/R_1=0.43$ and $\Delta=0.22$. For the critically damped waves $R/R_1=1$ and $t_2/t_m=2.68$.

An infinite number of circuits and voltages will produce any possible wave, and at the start one constant must be arbitrarily fixed. Usually the first selected constant is either the impulse-generator capacitance or voltage, but in some circumstances the limiting value might be inductance or resistance. Figure 3 shows two waves for which the impulse-generator capacitance was fixed and the remaining constants determined by use of the curves in Figure 2. It is seen that the two waves are not greatly different, but considerably more charge was required for the critically damped wave. For any nonoscillatory wave, the area under the ampere–time wave in amperes seconds is equal to the charge CE (C in farads and E in volts) but for oscillatory waves an integration for the first half cycle shows the ampere-seconds to be $CE(1+\Delta)$, and providing the resistance can be kept low enough, it is possible to get in the first half cycle nearly twice the ampere-seconds originally stored in the capacitance. This means, however, that the wave will oscillate for many half cycles, which frequently is not a desirable condition.

Empirical Calculations to Include Nonlinear Resistance of Arrester

Valve-type lightning arresters are designed to have low resistance at high currents and high resistance at low currents, and rigorous calculations of circuits containing such resistances are not possible. Figure 4 shows the types of waves which can be obtained in the circuit shown in Figure 1b where the variations in waves are caused only by variations in the charging voltage. Considering only the first half cycle, the current waves are remarkably similar in shape and are all approximately 12.5x22-microsecond waves. This ratio of t_2/t_m of about 1.75 is typical of impulse-generator circuits in which the arrester-valve element comprises most of the resistance, and so the specified ratio of two for 5x10- or 10x20-microsecond waves can be fulfilled approximately without difficulty. If a closer agreement is desired, it can be obtained by using some additional constant resistance.

In addition it should be observed that the first quarter cycle is practically a sine wave and the time to crest of 12.5 microseconds is a close approximation of the calculated time to crest for no resistance where:

$$t_m=0.5\pi\sqrt{LC} \qquad (4)$$

which gives $0.5\pi\sqrt{4.41\times15.4}=13$ microseconds. In Figure 5 are plotted the crest measurements of current and voltage from Figure 4, and in addition the ratios E/E_m and $I_m t_2/CE$.

The curves for I_m and E_m apply only for the circuit constants listed for Figure 4, but the ratios E/E_m and $I_m t_2/CE$ are universal in application for circuits wherein the resistance is chiefly arrester valve element. The absolute magnitudes and durations are immaterial for these ratios which depend only upon the wave shapes. The points for the ratios are identified with letters A–F corresponding to the oscillograms A–F in Figure 4. Hence, in any circuit if the wave shape of Figure 4E is desired, E/E_m must be 1.97. and $I_m t_2/CE$ must be 1.31. In the calculation of such a circuit, it is necessary to know or assume the maximum voltage across the arrester and resistance expected at the desired current. The following example shows the general method of attack.

Example

A 75-kv impulse generator is available with a maximum capacitance of seven microfarads and a minimum inductance of two microhenrys. Determine if this equipment is capable of producing a 100,000-ampere 5x10-microsecond discharge through an arrester having approximately 18-kv crest on this wave. Here $I_m t_2/CE=1.9$.

The curve of $I_m t_2/CE$ in Figure 5 goes only to 1.8 so the desired wave, if at all

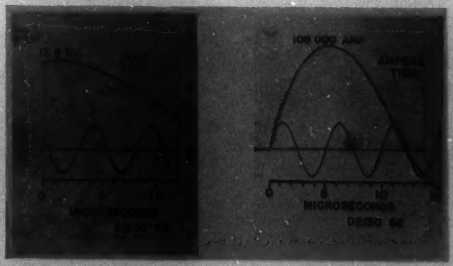

Figure 6. Voltage and current oscillograms for nominal 100,000 - ampere 5 x 10-microsecond current wave through a valve-type lightning arrester

Figure 7. Adjustable-capacitance impulse generator number 1

Figure 9. Marx-circuit impulse generator number 2

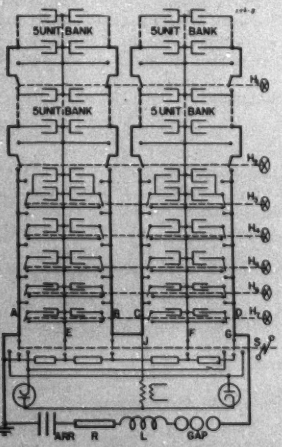

Figure 8. Circuit diagram of impulse generator number 1

Hand-operated switches H_1–H_5 throw capacitor units or banks on the busses *ABCD* or disconnect and short-circuit the terminals to the cases, *EF*. Solenoid-operated switch *S* has three positions: "left" for positive generator charge; "right" for negative generator charge; "middle" automatically grounds all live capacitor points except during charging periods

possible, will be more oscillatory than that shown in Figure 4A. Since some tolerance is allowed, a 4.7x9.4-microsecond wave is acceptable, which gives $I_m t_2/CE = 1.8$. Hence there is sufficient charge available to produce a 4.7x9.4-microsecond wave similar in shape to Figure 4A.

Using equation 4, $t_m = 0.5\pi\sqrt{LC} = 5.9$ microseconds, which is close enough for practical purposes.

For $I_m t_2/CE = 1.8$, the corresponding value of E/E_m is 3.38. This means that sufficient additional resistance should be added to the circuit so that $E_m = 75/3.38 = 22$ kv.

Figure 6 shows waves actually produced under the conditions specified in the above example. However, no resistance was added, so that for the waves of Figure 6 the current is higher and the oscillations greater than in the example.

The foregoing example shows that it is not always possible to fulfill the exact requirements determined by calculation, and in order to test various types and ratings of arresters over a range of currents and wave shapes, the impulse-generator constants and charging voltage must be adjustable over a wide range.

When several ratings of arresters are to be tested with the same wave, the circuit adjustments are minimized by setting up to test the highest rating first, and when other ratings of lower internal resistance are substituted, sufficient resistance is added to keep the total resistance constant.

Often it is found impossible, with existing equipment, to get aperiodic waves coming rapidly to zero as in Figure 4E. If the maximum charging voltage E is too low for a particular arrester rating, the waves will look like Figure 4F. If there is current to spare, the voltage wave can be brought down to zero by the use of a constant resistor in parallel with the arrester or generator capacitance. If the product CE is too small to produce the required wave like Figure 4E, the current can be increased in low ratings of arresters by letting it oscillate somewhat as was done in Figure 6 or Figure 4 (A–D).

Calculation for a Wave of Specified Crest and Nominal Steepness

For a wave specified by steepness instead of duration, it is only necessary to redesignate it in the usual way and calculate the circuit constants as previously shown. For circuits where R is low compared to R_T, the first quarter cycle is almost a sine wave. The nominal steepness, or the slope of the line through the

10 per cent and 90 per cent points, is approximately

$$\text{Nominal steepness} = 1.2I_m/t_m \quad (5)$$

or with $t_2/t_m = 1.75$ as in the waves of Figure 4

$$\text{Nominal steepness} = 2.1I_m/t_2 \quad (6)$$

For critically damped waves in circuits where R_A is low compared to R_T, similar approximate equations are

$$\text{Nominal steepness} = 1.4I_m/t_m \quad (7)$$

or

$$\text{Nominal steepness} = 3.7I_m/t_2 \quad (8)$$

for intermediate wave shapes an approximate equation is

$$\text{Nominal steepness} = 1.3I_m/t_m \quad (9)$$

and the equation in terms of t_2 can be found using the ratios of t_2/t_m in Figure 2.

Hence, using the equations 5 to 9 any wave based on crest and nominal steepness can be redesignated by crest and duration and calculations made as before.

Control of Impulse-Current Wave Shapes in General Testing

The calculating methods here presented are also applicable where nonlinear resistances, such as Thyrite, are used to control impulse-current wave shapes.[12,13] The use of such resistors permits higher crest currents without oscillation, and shorter wave tails, than can be obtained by use of constant resistance.

Description of Impulse Generators

It is evident from the foregoing material that lightning arrester impulse testing requires an extended range of circuit constants and unless the various circuits can be conveniently and quickly set up, much valuable time will be lost. In addition to the very high voltage and very high current impulse generators necessary for special tests on lightning arresters, there have been built during the last few years four generators at the continuous disposal of the lightning arrester department in Pittsfield.

Generator Number 1 for General Testing

Generator number 1 is shown in Figure 7 with part of the steel panels removed. The capacitors are all Pyranol-filled 75-kv units especially designed to have low inductance and to withstand repeated short-circuit currents. All units have mid-points tied to the cases. There are 28 capacitors rated 0.24 microfarad and 4 trimmers for fine adjustments rated 0.06 microfarad. The charge and discharge circuits are connected to two pairs of copper-tubing busses which may be operated in series for 150 kv or in parallel for 75 kv. The capacitors are mounted on two three-deck steel frameworks insulated from ground and each other. At 150 kv connection, the cases of capacitors in the front framework are at 112.5 kv and those in the back framework are at 37.5 kv. The handwheels shown in Figure 7 throw two or more capacitors on the lower busses or short circuit them to their respective frameworks. The capacitors in the two upper decks are permanently bussed in parallel but they can be connected either to the lower busses or short-circuited to the framework. The charging equipment is located on top of the steel housing, and the large cylinder contains a combination polarity reversing switch and ground switch which grounds all busses and frameworks except during the charging period.

Figure 8 shows the elementary circuit diagram for the 150-kv connection. For clarity none of the hand-operated switches H_1–H_7 are shown completely closed, but H_1 and H_3, when thrown to the indicated position, connect the two upper decks to the busses $ABCD$ while the capacitors in the lower deck are all removed from the busses and short-circuited by the switches H_2–H_7. By means of the switches any capacitance from 0.04 to 1.75 microfarads in steps of 0.04 microfarad can be instantly selected for 150-kv operation. For 75-kv operation switches (not shown in Figure 8) connect bus D to bus A and mid-point E to mid-point F. Also G is moved from D to BC and J from BC to EF. With these connections the capacitance can be varied from 0.16 to 7 microfarads in steps of 0.16 microfarad. For very long waves, all the capacitor bushings can be bussed together, using the cases for the return circuit, and then 28 microfarads can be obtained for charging voltages up to 37.5 kv.

Tests at moderate currents are made in the oscillograph room at the rear of the generator. High-current tests require short leads and are made inside the steel housing. Some of the tapped resistance and inductance control elements are shown hanging on the wall inside the door. The minimum discharge inductance is about two microhenrys and tests up to 100 kiloamperes can be made on low-voltage arresters. The oscillograms of Figure 6 were obtained using this generator.

The advantages of this impulse generator are:

1. *Safety.* No power can be applied until all safety gates are closed and all capacitance parts are grounded after every discharge.

2. *Convenience.* Capacitance and voltage are variable over wide ranges with little effort. The polarity can be changed by the flip of a switch. The three-electrode gap spacing is controlled by a wooden shaft extending into the oscillograph room, and the charging-voltage control is located on the oscillograph table.

3. *Reliability.* Several years of service without trouble have demonstrated its reliability.

4. *Compactness.* A minimum of floor space is used, the dimensions being 6½ by 12 feet.

5. *Totally Enclosed.* The steel housing eliminates stray electrostatic fields, and the exterior is neat even when destructive tests are being made inside. It also reduces the noise when high-current tests are being made.

Generator Number 2 for General and High-Voltage Testing

Impulse generator number 2 has a 600-kv six-stage Marx circuit as shown in Figure 9. The Pyranol-filled capacitors are rated 2.2 microfarads at 25 kv and have but one bushing with the case serving as the other terminal. Each stage consists of two groups of four capacitors in series. The primary groups are shown on the left in Figure 9 and the secondary groups at the right can be connected in parallel or short-circuited and left with cases floating. The charging resistors and interstage sphere gaps are mounted on the vertical wooden box at the extreme left. By means of switches the generator can be connected conveniently to operate at reduced voltage and high capacitance, and, if desired, part of the capacitance can be omitted. The following combinations can be obtained with either polarity and any voltage up to the maximum listed:

Maximum Kv	Microfarads Available
50	1.1 to 26 in steps of 1.1
100	0.55 to 6.60 in steps of 0.55
200	0.28 . . . 0.55 . . . 0.82 . . . 1.1 . . . 1.6
300	0.18 . . . 0.37 . . . 0.73
400	0.14 . . . 0.28
500	0.11 . . . 0.22
600	0.09 . . . 0.18

The advantages of this generator over number 1 are its higher voltage and greater energy. Tests can be made on arresters up to 75-kv rating at 5,000 amperes, 10x20-microsecond waves, and at appreciably greater currents on lower ratings. Its minimum inductance is higher than for generator number 1 since the Marx circuit necessitates longer connections. Because the minimum inductance at 100 kv is about 3.5 microhenrys, generator number 2 will not produce as high currents as generator number 1 even though it contains nearly twice the energy.

Figure 10. Adjustable-capacitance impulse generator number 3 used for operating-duty power tests

However, for a wide range of voltage and moderate currents of 50 kiloamperes or less, it supplements the other generator. The oscillograms in Figure 4 and all those in a contemporary paper[14] describing a new oscillograph were produced using this generator.

Generators Numbers 3 and 4 Used for Operating-Duty Tests

For convenience, two additional impulse generators are used for operating-duty power tests. Generator number 3, shown in Figure 10, consists of two rows of capacitors which can be connected in parallel or series for 50- or 100-kv operation. The usual connection is 100 kv, and by means of the handwheel-operated switches, the capacitance can be adjusted from 0.125 to 1.9 microfarads in steps of 0.125 microfarad. Units not in use are short-circuited by the switches, but the cases remain at the midtap potential of those in use. All live parts are automatically grounded except when the generator is on charge. The voltage and gap settings are easily adjustable, and the polarity can be reversed if desired.

Generator number 4 is similar in construction and rating to number 3. Either one is capable of sending a 10,000-ampere 10x20-microsecond wave through a 12.5-kv arrester. Number 3 is used for routine tests with a power supply of 500 kva at 3, 6, 12, or 24 kv at 60 cycles, while number 4 is used with a supply of 2,500 kva at 7.5 or 15 kv.

In addition to the four impulse generators described, there are available in the high-voltage engineering laboratory impulse generators rated up to 5,000 kv and a high-current generator[11] which can be connected for a maximum 6.2 microfarads at 150 kv, 14 microfarads at 100 kv, or 56 microfarads at 50 kv. This high-current generator has very low inductance and can produce currents up to 250 kiloamperes. It can be used for regular impulse tests or for operating-duty power tests with either of the power sources used with generators number 3 or 4.

Summary

1. Thorough testing of lightning arresters requires a wide variety of impulse-current waves.

2. The strictly mathematical calculation of circuit constants to produce such waves is limited to the few cases where the circuit resistance is constant.

3. Valve-type lightning arresters have a resistance that is intentionally a function of voltage or current and the determination of the constants of circuits containing valve elements must be done experimentally.

4. Impulse-current waves of the same shape but various durations and magnitudes have circuit constants where $R_T/\sqrt{4L/C}$ is fixed.

5. Once the circuit constants are determined for a particular wave, the constants for similar waves of other magnitudes and durations are easily calculated.

6. The curves of Figure 5 facilitate such calculations for the wide range of wave shapes shown in Figure 4.

7. The testing of various types and ratings of arresters with a number of different waves, requires extremely flexible impulse-generator circuits.

8. Ordinarily the impulse-generator capacitance is the most difficult circuit constant to adjust, but four special impulse generators are described having capacitance values easily adjustable over a wide range. Several years of experience with these generators, and the previously mentioned calculating methods, show that constants for any desired wave, within the capabilities of the equipment, can be computed and set up easily and quickly.

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Analytical Treatment for Establishing Load-Cycle Ratings of Ignitrons

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THE ignitron offers unique possibilities as a control element for high instantaneous alternating demand currents. The demand current is limited only by the capacity of the ionized vapor to conduct the current from the mercury pool to the anode and by probability of arc back, which increases as the peak current conducted by the tube increases. The design of ignitron tubes is a compromise between these two factors. Design for low arc-back rate usually results in anode baffles and shields which tend to increase the deionizing properties of the tube and thus decrease the peak current-carrying capacity.

The above consideration and not failure of the cathode to emit electrons limits the peak current that can be controlled by an ignitron. For various classes of control service, such as resistance welder control, the arc-back problem is minimized by the characteristics of the circuit, and the tubes are designed without baffles or other constrictions. Therefore, the peak to average current ratios can assume higher values than are customary in gas- or vapor-filled tubes in other classes of service.

Experience has indicated that the average current ratings within the above peak current limitation are limited mainly by thermal considerations. These limitations are relatively easy to determine under conditions of continuous operation. One operates the tube for a reasonable period of time with the circuit constants and the firing phase chosen so as to place the maximum arc-back stress on the tube at regularly increasing current steps until arc back or loss of control occurs and then backs off for a reasonable factor of safety to establish a point on the rating curve at 100 per cent duty.

By measuring the loss in the tube at this current the energy which can safely be dissipated by the tube can be determined for continuous duty.

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However, tubes in general and welding tubes in particular are seldom operated at continuous duty. A large number of combinations of duty cycle and demand currents is possible for a given size ignitron and is used in commercial practice. It is, therefore, necessary to invent methods of determining rationally the rating of these tubes and presenting the data in a form which is capable of furnishing a definite figure for the permissible demand current at any conceivable combination of current and duty.

Obviously, the tube cannot be economically tested for all the various possible combinations. The present paper describes a method which can be used to interpolate or extrapolate to obtain ratings for any combination of intermittent duty. This method consists in operating the tube at a simple on- and off-duty cycle at a high current value and determining an intermittent rating point in addition to the continuous rating point determined as described above.

Curves of arc drop as a function of demand current are also determined. It will in general be found that the average loss in the tube for equal excellence of operation at high currents will be less than that at continuous duty. It is assumed that this difference in heat-dissipation quality is due to the intermittent production of heat in the tube and is a function of an equivalent "thermal time constant" similar to the equivalent electrical quantity. The accuracy of the method can be checked in practice by repeating the determination of the thermal constants using several different duty cycles. The authors realize that the variation of the temperature of the simple model treated in the following discussion does not completely describe the thermal cycle of an ignitron but believe that by its use a close enough approximation can be achieved for the degree of accuracy required.

Similar methods are now in use employing the familiar concept of maximum averaging time and are satisfactory enough for most purposes but give results that seem artificial under certain conditions. It is hoped that the present paper will be regarded as a theoretical approach to a rating method based on more nearly correct physical principles.

Thermal Action of Equivalent Model

In approaching the problems of establishing ratings for ignitrons on intermittent duty, equations are developed for a model system. This system is one in which heat is lost by conduction, and the heat loss is therefore proportional to the first power of the temperature difference between the model and the cooling medium. The model is considered to be a small mass of metal in which the temperature at any time is uniform throughout. The mass of metal is surrounded by a cooling medium to which heat from the metal is lost by conduction.

The case to be considered is one where energy is put into the system in equal amounts at regularly spaced intervals. During the time that energy is being put into the system the temperature rises, although some heat is lost by conduction. During the off period when no energy is being supplied, the temperature falls.

To develop the general equation for intermittent loading it is necessary to set up relations between the temperature θ' and the energy input W and time t for both the heating and cooling portions of the cycle. The differential equation for the temperature, while energy is being supplied at the rate W, is

$$CMd\theta' = Wdt - K(\theta' - \theta_0)dt$$

If temperature rise $\theta' - \theta_0$ is replaced by θ, and consequently $d\theta'$ by $d\theta$, the equation will express the temperature θ referred to the temperature of the cooling medium as zero, giving

$$CMd\theta = Wdt - K\theta dt \qquad (1)$$

where

θ = the temperature of the heated mass referred to the cooling medium temperature as zero
W = average watts input during the heating period
C = specific heat of the metal
M = mass of the metal
K = thermal conduction constant

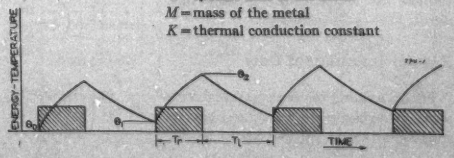

Figure 1. Temperature of model as function of time, with rectangular-wave-form energy input

Rearranging the terms in equation 1 and integrating:

$$\log_\epsilon (W-K\theta) = \text{constant} - \frac{K}{CM} t$$

and since at $t=0$, $\theta=\theta_1$, the constant $=\log_\epsilon (W-K\theta_1)$, where θ_1 is the temperature at the beginning of the heating period. Solving for θ, the temperature at any time during the heating period is given by

$$\theta = \left(\theta_1 - \frac{W}{K}\right)\epsilon^{-\frac{t}{T_c}} + \frac{W}{K} \quad \text{(heating period)} \quad (2)$$

where

$$T_c = \frac{MC}{K} = \text{time constant}$$

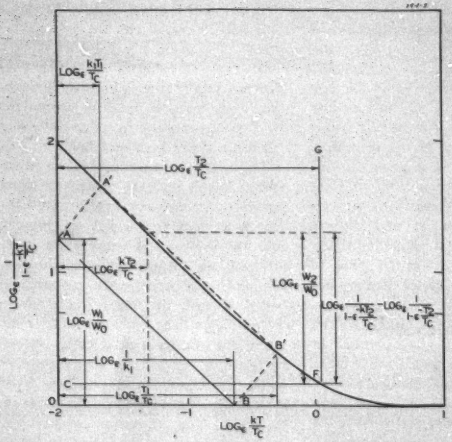

Figure 2 (left). Chart illustrating graphical method of determining rating of model as function of duty cycle and thermal time constant

The temperature during the cooling period can be found from equation 1 by letting $W=0$. This gives

$$\log_\epsilon \theta = \text{constant} - \frac{t}{T_c}$$

At $t=0$ that is, at the end of a heating period $\theta=\theta_2$ as given by equation 2 when t equals T_r, the length of the heating period. This makes the constant equal to $\log_\epsilon \theta_2$ and gives

$$\theta = \theta_2 \epsilon^{-\frac{t}{T_c}} \quad \text{(cooling period)} \quad (3)$$

Equations 2 and 3 are sufficient to determine the temperature θ at any time during load-cycle operation.

Regular Intermittent Duty

Figure 1 shows the temperature θ for a series of regularly spaced equal impulses supplied as shown by the shaded blocks. The time factor $k=T_r/(T_r+T_i)$ is the ratio of the time during which the load is on, to the period or length of the cycle. On the initial cycle θ_1 is equal to θ_0, and θ_2 is given by equation 2 where t is set equal to T_r. For each successive heating period a different value of θ_1 must be used, and this is of course the value of θ at the end of the previous cooling period. After a sufficient number of impulses equilibrium will be reached, and then all the successive values of θ_1 will be equal and the values of θ_2 will also be equal. This simply means that in each "off" period the system loses just the amount of heat which it gained in the previous "on" period.

The allowed value of the watts W during the on period is determined by the maximum temperature allowed. Therefore the value of θ_2 must be found after equilibrium has been reached. For this condition $\theta=\theta_1$ at $t=T_i$ in equation 3 and rearranging

$$\theta_2 = \theta_1 \epsilon^{\frac{T_i}{T_c}} \quad (4)$$

Also, θ_2 in equation 4 must equal θ from equation 2 when $t=T_r$ and therefore

$$\theta_2 = \theta_1 \epsilon^{\frac{T_i}{T_c}} = \left(\theta_1 - \frac{W}{K}\right)\epsilon^{-\frac{T_r}{T_c}} + \frac{W}{K} \quad (5)$$

Solving for θ_1

$$\theta_1 = \frac{W}{K}\left(\frac{1-\epsilon^{-\frac{T_r}{T_c}}}{1-\epsilon^{-\frac{T_r+T_i}{T_c}}}\right) \quad (6)$$

Substituting this value of θ_1 in the second term of equation 5

$$\theta_2 = \frac{W}{K}\left(\frac{1-\epsilon^{-\frac{T_r}{T_c}}}{1-\epsilon^{-\frac{T_r+T_i}{T_c}}}\right)\epsilon^{\frac{T_i}{T_c}}$$

and simplifying

$$\theta_2 = \frac{W}{K}\left(\frac{1-\epsilon^{-\frac{T_r}{T_c}}}{1-\epsilon^{-\frac{T_r+T_i}{T_c}}}\right) \quad (7)$$

We may now designate the period of the intermittent cycle, (T_r+T_i), by the symbol T as is customary. Then since the ratio of conducting time to the period $T_r/(T_r+T_i)=T_r/T=k$, equation 7 becomes

$$\theta_2 = \frac{W}{K}\left(\frac{1-\epsilon^{-\frac{kT}{T_c}}}{1-\epsilon^{-\frac{T}{T_c}}}\right) \quad (8)$$

Equation 8 gives the value of the maximum temperature reached at equilibrium in terms of the watts input W, the period T, and the "on" time $kT=T_r$. The safe or allowed value of θ_2 can be obtained from the allowed watts, W_0, for continuous loading. In this case $k=1$ and equation 8 gives

$$\theta_{2\,max} = \frac{W_0}{K} \quad (9)$$

If the requirement for safe operation is that θ_2 shall never exceed W_0/K, it can be replaced by this value in equation 8, giving

$$\frac{W}{W_0} = \left(\frac{1-\epsilon^{-\frac{T}{T_c}}}{1-\epsilon^{-\frac{kT}{T_c}}}\right) \quad (10)$$

This equation gives the allowed value of input watts W, which can be used for a time, $T_r=kT$ for a repeated loading cycle of period T.

In order to use a graphical construc-

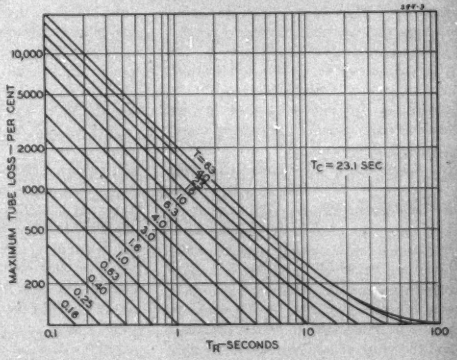

Figure 3 (right). Curve showing rating of model at a given thermal time constant equal to 23.1 seconds

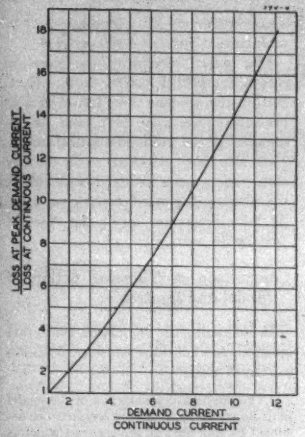

Figure 4. Curve showing increase in tube loss as function of increase in tube-demand current

tion from which the value of time constant can be determined, and rating curves can be laid out, it is convenient to consider equation 10 in the following manner. For two values of k, but the same period T

$$\frac{W_1}{W_0}=\frac{1-\epsilon^{-\frac{T}{T_c}}}{1-\epsilon^{-\frac{k_1T}{T_c}}} \tag{11}$$

and

$$\frac{W_2}{W_0}=\frac{1-\epsilon^{-\frac{T}{T_c}}}{1-\epsilon^{-\frac{k_2T}{T_c}}} \tag{12}$$

Dividing equation 11 by equation 12

$$\frac{W_1}{W_2}=\frac{1-\epsilon^{-\frac{k_1T}{T_c}}}{1-\epsilon^{-\frac{k_2T}{T_c}}} \tag{13}$$

This expression suggests the relations

$$W_1\propto\frac{1}{1-\epsilon^{-\frac{k_1T}{T_c}}} \tag{14}$$

and

$$W_2\propto\frac{1}{1-\epsilon^{-\frac{k_2T}{T_c}}} \tag{15}$$

Figure 2 shows $\dfrac{1}{1-\epsilon^{-\frac{kT}{T_c}}}$ plotted against kT/T_c. This curve will give the value of W/W_0 by dividing the value for k_1T/T_c by that for T/T_c. If the value of T_c is known, specific values of T_r and T can also be derived from this curve.

Application to Ignitron Ratings

As an illustration of the use of this method, rating curves will be obtained for a small water-cooled metal ignitron. Since all of the energy loss is eventually transferred to the cooling water, the problem will be regarded as one where heat is lost by conduction, as in the system covered by the preceding sections.

The test data were as follows:

1. Continuous duty
Tube loss at satisfactory operation $= W_0$
2. Intermittent duty
Tube loss at equally satisfactory operation $= W_1$
$T_r = 0.5$ second
$T = 11.1$ seconds
$k = 0.0448$
3. $\dfrac{W_1}{W_0}=18.0$

To find T_c substitute in equation 10

$$\frac{W_1}{W_0}=18.0=\frac{1-\epsilon^{-\frac{11.1}{T_c}}}{1-\epsilon^{-0.0448\left(\frac{11.1}{T_c}\right)}}$$

This equation can be solved by trial for $11.1/T_c$. The solution is 0.48 ± 0.005

or $T_c=\dfrac{11.1}{0.48\pm0.005}=23.1\pm0.3$ seconds

Since ignitrons are rectifiers the current conducted by them on a-c circuits is not continuous but consists of a series of half sine waves. The foregoing theory assumes that this intermittent power input can be represented by a continuous function of the time. The accuracy of this assumption can be checked by use of equation 4 where

$$\frac{\theta_2}{\theta_1}=\epsilon^{\frac{T_i}{T_c}}$$

Using the data of the above example and a line frequency of 60 cycles per second

$$\frac{T_i}{T_c}=\frac{\frac{1}{120}}{23.1}=0.00036$$

and therefore

$$\frac{\theta_2}{\theta_1}=1.0004$$

This result indicates that in this case the variation in temperature due to the rectified current pulsation in the tube can be neglected in comparison with the longer period load cycling.

Graphical Calculation and Presentation of Data

Assume that test data are available to establish a rating at a given T and T_r, and that the ratio of the loss in the tube at continuous duty to that at the given duty is known, then the above method will permit the calculation of a value for the thermal time constant, T_c.

The thermal time constant will allow a system of interpolation of the results of the rating tests to other load cycles in a systematic way which is mathematically continuous. The present method, wherein a "maximum averaging time" is used, has the effect of limiting the maximum time of impulse to values less than the maximum averaging time even for demand current loads of only a few per cent higher than continuous load rating. This new method goes over smoothly to the continuous rating.

Graphical Calculation of T_c

The function $\dfrac{1}{1-\epsilon^{-\frac{kT}{T_c}}}$ is plotted in Figure 2 on logarithmic co-ordinate scales. Our test data give us two values of tube loss (W_1 and W_0) at two values of T_r equal to kT_1 and T_1 respectively, where T_1 is the impulse period of the rating test. It is desired to determine the value of T_c which fixes the scale of the diagram, Figure 2, for the particular tube being rated.

From equation 11 we can write

$$\log_\epsilon\frac{W_1}{W_0}=\log_\epsilon\frac{1}{1-\epsilon^{-\frac{k_1T_1}{T_c}}}-\log_\epsilon\frac{1}{1-\epsilon^{-\frac{T_1}{T_c}}}$$

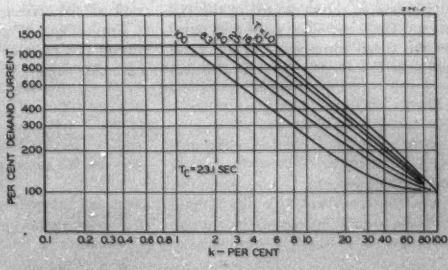

Figure 5. Example family of tube-rating curves as function of impulse time, T_r, and impulse period, T, for thermal time constant, $T_c=23.1$ seconds. Calculated from Figures 3 and 4

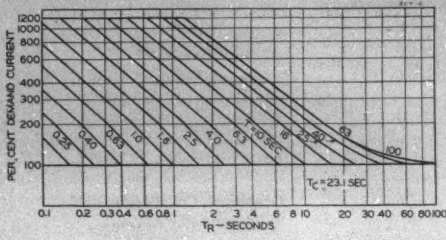

Figure 6. Example family of tube-rating curves as function of per cent duty and impulse period. Calculated from Figure 4

It is seen that the relationship existing between W_1/W_0 and k_1 for given values of T and T_c is in general given by the first term of the above equation, since when T and T_c are fixed, the second term is independent of k_1 and becomes of a constant value which can be subtracted graphically as is done in Figure 2. In order to determine T_c, it is necessary to determine the amount to be subtracted from the ordinate of the curve in Figure 2, in order to make the remainder of the curve fit the conditions as laid down by the test.

This can be done most easily in the following manner. Since the argument of the plotted function is kT/T_c and since the time difference of the test points is defined by k_1, the difference in the abscissa of the test points on the curve at A' and B', when found, must be equal to

$$\log_\epsilon \frac{T_1}{T_c} - \log_\epsilon \frac{k_1 T_1}{T_c} = -\log_\epsilon k_1 = \log_\epsilon \frac{1}{k_1}$$

Therefore, the slope of the chord at $A'B'$ will be

$$\frac{\log_\epsilon \frac{W_1}{W_0}}{\log_\epsilon \frac{1}{k_1}}$$

A convenient way to lay off this slope is to draw it in a corner of the diagram as shown at AB. In order to fix T_c, it is only necessary to find two points on the curve separated the same distance and at the same slope as the hypotenuse of the triangle AOB. This is done for the example case as shown dotted in the diagram. The lower point at B' thus found on the curve corresponds to $\log T_1/T_c$ and since T_1 is fixed by the test conditions T_c can be calculated. This value can be checked by substitution in formula 10.

Graphical Presentation of Rating Data

After T_c is determined, the rating curve for any other impulse period T_2 can be laid out. The point corresponding to $k=1$ will lie at F, distant $\log T_2/T_c$ from the vertical axis of the diagram. Lines CF and GF form the axes for a new curve whose abscissa is proportional to $\log kT_2$ and whose ordinates are proportional to $\log W_2/W_0$ as shown on the diagram.

By tracing these curves on Figure 3 the curves shown are obtained. This gives a family of curves showing the permissible ratio of tube heating loss to loss at continuous duty at a number of values as a function of $kT=T_r$. It will be noted that when $T=T_r$ the W/W_0 ratio $=1$. At low values of T the curves are nearly straight lines, but at large values they become curved and are not spaced as far apart as for corresponding lower values of T. A value of T is reached (63 in the curve) where no further advantage is gained by long cooling periods except for low values of demand ($T=100$ in the curve).

The above curve pertains only to actual energy loss in the tube. This can be translated into current values by plotting the corresponding current values as transformed by curve Figure 4, which gives the loss ratio between continuous rating and demand current as a function of the ratio of the corresponding currents.

Curve Figure 5 gives the rating ratio curves as a function of T_r and T for the example value of $T_c=23.1$ seconds. These curves are sharply cut off at the peak current value of 1,200 per cent.

The same information is given in curve Figure 6 in another form. Here, each of the abscissa is in values of k as per cent of the value of T used as parameter on the individual rating curves. This may be compared more directly with the present rating curves where the abscissa is plotted in per cent duty. T here compares with the present "maximum averaging time."

Comparison of Thermal Action of Model and Ignitron

In comparing the model with the actual ignitron, the following considerations are worthy of note:

1. The temperature variation of the model finds no counterpart in any temperature assumed by any part of the ignitron which is susceptible to measurement. The nearest thing might conceivably be the equivalent temperature of the mercury vapor in the tube. Since this cannot be measured, the equations are set up so as not to make a numerical knowledge of any temperature necessary.

2. The criterion is assumed to be that no duty cycle shall impose a higher value of equivalent temperature on the tube than that determined to be safe at continuous operation. This assumption requires considerably more investigation than the authors have been able to do. However, since the action of ionic devices is very rapid, it would seem reasonable that any effect on arc back due to the equivalent temperature could act in such a short time that instantaneous values of this temperature would be critical.

Summary

The above theory suggests a method of defining the intermittent rating of an ignitron tube through the use of a so-called time constant. This method results in a smooth transition from intermittent to continuous duty ratings. It is possible to adapt the time-constant concept to the calculation of permissible ratings for more complicated duty cycles than are considered in the present paper.

The authors hope to be able, in the future, to check the actual performance of tubes against the above theory, especially at values approaching the continuous current rating.

Modern Cathode-Ray Oscillograph for Testing Lightning Arresters

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THIS oscillograph was designed to meet the specialized needs of a group that uses the cathode-ray oscillograph as the principal tool in the study of transients in lightning-arrester development. The instrument is desirable for many purposes, especially those requiring very high writing speeds in connection with nonrepetitive transients where photographic records must be obtained. Other requirements of primary importance in the design were convenience of operation; accuracy of measurement of current, voltage, and time; accuracy of the timing; and linearity and rectilinearity of the plate pattern.

The cathode-ray oscillograph with the film in the vacuum was first described by Dufour,[1] and improvements have been described by numerous investigators such as Rogowski and his associates,[2] Burch and Whelpton,[3] Whipple,[4] Norinder,[5] to mention only a few.

General Description of the Oscillograph

The essential elements of any cathode-ray oscillograph include a cathode and anode operated in a vacuum to provide the electron beam; deflecting means; and a photographic film or fluorescent screen. The electrons from the cathode are accelerated to a high velocity by the cathode voltage, pass through an aperture in the anode, pass between the deflecting plates or coils, and impinge on the film or screen. The oscillograph described in this paper includes these elements and additional elements to make the instrument suitable for recording transients of extremely short duration. A focusing coil increases the intensity of the beam, trapping plates control its duration independently of the cathode voltage, and high-voltage circuits apply the cathode and beam-trapping voltages in the correct split-micro second sequence. An automatic regulator holds the oscillograph pressure at the desired value. The cathode voltage is held constant by a voltage regulator. These features that provide ease of control, fidelity of recording, and high writing speed are described more completely.

A view of the instrument is shown in Figure 1 and a diagram of the high-voltage circuits in Figure 6. The cold cathode is operated at 60 to 80 kv obtained from an impulse generator. The film chamber, deflection tube, and beam-trap tube are metal; both metal and glass cathode tubes have been satisfactory. The deflecting tube contains a pair of sweep plates to move the beam along the time axis and a pair of deflection plates to move the beam in a direction perpendicular to the sweep. The trap, consisting of three pairs of parallel plates, is placed between the anode and focusing coil.

Vacuum System

The vacuum system, Figure 2, was designed to maintain a pressure in the cathode tube sufficiently high to give a copious discharge, while the pressure in the remainder of the oscillograph is low enough to minimize scattering of the beam and fogging of the film.[6] This differential in pressure is provided by a controlled leak from the atmosphere to the cathode tube and by the restriction in flow of air from the cathode tube to the remainder of the oscillograph at the anode hole. The direction of air flow isolates the cathode tube from condensation-pump vapor without the necessity of a trap.

When the oscillograph is pumped down from atmospheric pressure, a rough vacuum is first obtained with the condensation pump by-passed through valve 5; valves 3 and 4 open, and valves 1 and 2 closed. To obtain a higher vacuum, valve 5 is then closed, and valves 6 and 7 are opened by a switch controlling the interlocked solenoids. The condensation-pump heater circuit and valve 5 will be opened and valves 6 and 7 closed by a flow switch if the cooling water for the condensation pump stops.

After the entire oscillograph has been evacuated to a low pressure, valve 3 is closed and valves 1 and 2 are manually adjusted to allow a gradual increase in the cathode-tube pressure. At this time, the vacuum system is switched to automatic operation with valves 3 and 4 controlled by a contact-making vacuum gauge to regulate the rate of leak to the discharge tube. Interlocked solenoids normally hold valve 3 closed and valve 4 open. When the pressure in the discharge tube has increased to the desired value because of the leak, the gauge causes the momentary opening of valve 3 and closing of valve 4, reducing the leak-chamber pressure. The ratio of expansion to leak-chamber volume is about two per cent, and the pressure in the leak chamber is much greater than in the expansion chamber so the rate of leak to the discharge tube is also reduced by about two per cent by the operation of valves 3 and 4. The vacuum gauge continues these automatic adjustments in rate of leak as frequently as is necessary, up to three times per minute, to maintain pressure in the cathode tube within a tolerance of 0.1 micron. Sudden changes in cathode-tube pressure are prevented by the smoothing action of the leak chamber.

Focusing Coil

The focusing coil has a steel shroud and pole pieces to give a short magnetic field of uniform intensity over the aperture to minimize aberration. The focusing current is held constant, independent of variation in line voltage, by a gas regulator tube. The effect of the focusing coil on the beam intensity is shown in Figure 3 by comparing the 5-millimeter width of the 1000-volt calibration line taken with the focusing coil unenergized, with the 0.5-millimeter width of the dense zero line taken with the proper focusing coil current. A fine trace can be obtained with no focusing coil provided the anode hole is very small, but this greatly reduces the writing speed.

Beam Trap

There are three pairs of cross-connected beam-trapping plates, as described by Burch and Whelpton.[3] With perfectly balanced plates, voltages insufficient to trap the beam will not deflect it. Actually it is impossible to adjust the plates perfectly; therefore, the trapping voltage is kept to a minimum during the sweeping time. Voltages in excess of about one kilovolt deflect the beam so that it cannot pass through an aperture located between the two upper pairs of trapping plates. The beam is cut off below the anode except during a relatively short interval adequate for sweeping it across the film, and conse-

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quently fogging of the film is reduced. With impulse excitation of the cathode, a beam trap is not a necessity as with continuous excitation, but it is advantageous to cut the beam off while the cathode discharge is stabilizing and after the beam has been swept across the film.

Cathode-Voltage Regulator

The charge on the capacitors of the impulse generator supplying the cathode voltage is made independent of the supplyline voltage by a regulator of the electronic type. If variation of cathode voltage is permitted, the deflection will vary as is shown in Figure 4 by the two 1,600-volt calibration lines differing by three per cent which were taken with the regulator disconnected. Two zero lines were also taken but coincide since variations in cathode voltage do not affect the position of the zero line.

Elimination of Spurious Deflection

Magnetic fields deflect the beam, but a constant field, such as that of the earth, merely affects the position of the zero axis and is not objectionable. The synchronous switch (see Figure 6) prevents random timing of the oscillograph operation with respect to the periodic variation in magnetic field from nearby 60-cycle apparatus. It prevents errors such as are shown in Figure 5 by the separation of 0.5 millimeters between two zero lines taken with the switch stopped.

The metal deflection tube in this oscillograph prevents errors such as may occur in oscillographs with glass deflection tubes due to charges transferred from the beam to the glass walls.

The deflection and sweep plates were designed and adjusted so that the deflection produced by the two sets is at right angles and is proportional to the voltage.

High-Voltage Circuits and Sequence of Operation

It would be impossible to obtain oscillograms of nonrecurrent transients of short duration without proper timing of the cathode-voltage and sweep circuits of the oscillograph, and synchronization with the transient to be studied.

A push-button control starts a sequence of operations in the high-voltage circuit of Figure 6. These operations include:

1. Charging the cathode generator.
2. Application of voltage to the cathode.
3. Trapping the beam while the cathode discharge stabilizes.
4. Sweeping the beam across the film.
5. Initiation of the impulse generator so that discharge occurs during the sweep.
6. Holding the beam off the film after the sweep is completed.
7. Grounding the high-voltage circuits.

In order to obtain constant sweeping speed, the sweep plates are operated at equal voltages of opposite polarity with respect to ground. For this reason, much of the high-voltage circuit is symmetrical with respect to ground. The operation of this circuit is best explained by considering each step in the order of occurrence.

Cathode-Generator Charging Period

Operation of the control button starts the charging of the cathode generator. The Marx circuit capacitors C_g and the reservoir capacitor C_1 are charged to 20 kv, negative, and a positive charge of 20 kv is placed on the similar capacitors C_g' and C_1'. Simultaneously, the sweep-supply capacitors C_8 and C_8' in circuit 5 charge to equal voltages of opposite polarity through resistors R_{14} and R_{14}'. A fraction of this voltage, determined by the ratios of R_{14} to R_{15} and R_{14}' to R_{15}' in circuit 4 is applied to the sweep capacitors C_8 and C_8' to bias the cathode beam. Also a fraction of the voltage on the supply capacitor C_8 is applied to the beam-trap plates by the high-resistance potentiometer R_{22}, R_{23}, in circuit 8, compensated by capacitors C_{13}, C_{14} for fast response. Capacitor C_8 in circuit 3 is charged to 40 kv.

Application of Voltage to Cathode

When the capacitors of the cathode-voltage generator have been charged to the proper value of about 20 kv, the volt-

Figure 1. Oscillograph viewed from the front

A—To cathode generator
B—Cathode tube
C—Anode
D—Beam trap
E—Focusing coil
F—Deflection chamber
G—Film chamber
H—Vacuum-regulator gauge

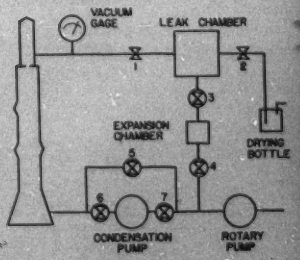


Figure 2 (right). Vacuum control system

Valves 1 and 2 are manually adjusted. Solenoid valves 3 and 4 are controlled by the contact-making vacuum gauge. Solenoid valves 5, 6, and 7 are interlocked

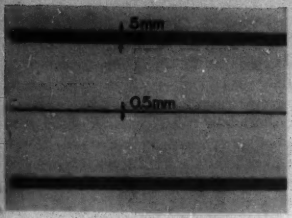


Figure 3. Effect of focusing

The focusing coil was unenergized for the 1,000-volt calibration lines, but was energized for the zero line

age regulator automatically opens the low-voltage charging circuit and releases the moving arms of the synchronous switch and the grounding contactor. The operating time of these switches is long compared with the longest sweeping time of the oscillograph. When the arms of the synchronous switch touch the middle pair of contacts, the cathode generator discharges as soon as the rotating arm reaches the closed position, which times the discharge with respect to the 60-cycle circuits. The gap G_1 discharges, and 80 kv negative is applied to the oscillograph cathode.

Gap G_2 discharges after an interval provided by the charging time of C_2 in circuit 1 for stabilization of the cathode discharge.

Initiation of the Impulse Generator

After G_2 sparks, gap G_3 is delayed by the time required to charge C_3 in circuit 2; the delay can be adjusted by the variable inductance. When G_3 sparks, an initiating impulse travels to the three-electrode gap of the generator[7] supplying the impulse to be measured. These circuits require careful adjustment to time the transient discharge to occur early in the period while the beam is crossing the film, which

Figure 4. Effect of variation in supply voltage on deflection

Oscillograms taken with cathode-voltage regulator disconnected

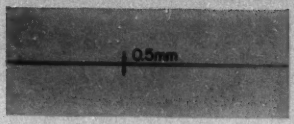


Figure 5. Effect of stray magnetic fields

Two zero lines taken with synchronous switch stopped; separation is caused by difference in instantaneous value of magnetic field from 60-cycle equipment

may be as short as 0.25 microsecond with a fast sweep.

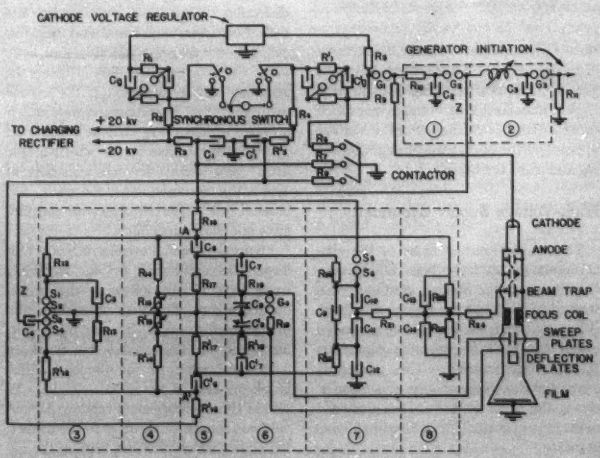
Removal of Beam-Trap Voltage

The sparking of G_2 applies voltage to the line Z terminated by capacitor C_4 in circuit 3. This voltage disturbs the balance of voltage across the four-electrode gap S_1–S_2–S_3–S_4, which sparks and grounds electrodes S_1 and S_4 simultaneously. The capacitor C_3 discharges through R_{13} and the four-electrode gap, thus insuring low arc resistance and thorough grounding. A four-electrode switching gap, not previously used in such circuits, was necessary rather than the usual three-electrode gap. The two end gaps S_1 and S_4 must operate at equal voltages of opposite polarity to give the necessary symmetry of circuits; another electrode S_5 provides the connection to ground, and hence a fourth initiating electrode S_3 was introduced.

The points A and A' in circuit 5 are grounded by the four-electrode gap. As a result, the beam-trap voltage is removed by the compensated potentiometer in circuit 8, and the beam appears between the deflection plates, but is held at the edge of the film by the charges acquired by C_8 and C_8' during the charging period.

Figure 6. High-voltage circuits

1—Sweep delay
2—Impulse-generator delay
3—Grounding
4—Deflection-plate bias
5—Supply
6—Sweep
7—Beam cutoff
8—Initial beam hold-off



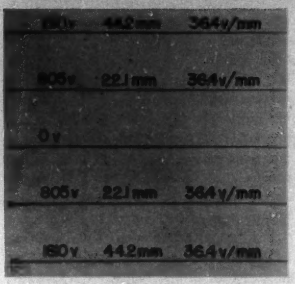


Figure 7. Consistency of deflection and absence of fogging

Five traces are superimposed on each of 5 lines. Superposition is possible because of the vacuum, cathode-voltage, and calibration-voltage regulators and the synchronous switch

Sweeping the Beam

Grounding of A and A' also puts 20 kv positive on R_{17} in circuit 5 and 20 kv negative on R_{17}' supplied from C_6 and C_6'. As a result, current flows through the blocking capacitors C_7 and C_7', resistors R_{15} and

R_{18}', and into sweep capacitors C_8 and C_8', which supply balanced positive and negative voltages to the deflection plates. This current reverses the sweep-plate bias voltage so that the beam is swept across the film. The plate voltage is limited by sparkover of G_4 after which R_{19} maintains sufficient voltage to hold the beam off the film.

Beam Cut-off

Voltage on R_{17} and R_{17}' also causes current to flow through R_{20}, C_9, R_{20}' in circuit 7 which builds up a positive voltage on S_4, while S_4 is held at 20 kv, negative, by the reservoir capacitor C_1. During the sweep when C_8 was charging, the voltage on the beam trap was unchanged, because circuit 7 is symmetrical and balanced to ground

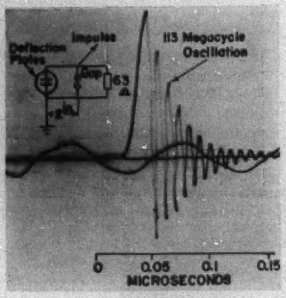


Figure 8. High writing speed

Voltage oscillation in a small circuit following gap breakdown. Timing wave is 10 megacycles; sweeping speed is 44 centimeters per microsecond and the maximum writing speed is 3,000 centimeters per microsecond

since C_{12} compensates for the capacitance of the gap S_3–S_4. After a time delay, the gap S_3–S_4 sparks, applying voltage from C_1 that unbalances the voltages on capacitors C_{10} and C_{11}. A fraction of this voltage appears on the beam trap through R_{21} and R_{24} and traps the beam.

High-Voltage Supply Grounded

The moving-contact arms of the synchronous switch have been falling continually since the holding contactor was tripped by the cathode-voltage regulator. When contact is made with the grounded stops, the cathode-generator capacitors C_9, C_9' are grounded. The grounding contactor was released also and when it closes, the other capacitors are grounded so that the operator can make adjustments in safety.

Operating Controls

Oscillator timing waves are provided by five pretuned circuits covering the range of 0.1 to 10 megacycles per second. Sweeping speeds which cross the film in 0.25 to 200 microseconds may be selected by means of a tap switch varying C_8 and C_8'. The maximum convenient sweeping speed is about 45 centimeters per microsecond. Special deflecting-plate switches change the circuits for recording the several functions such as the timing wave, calibration voltage, and impulse voltage or current. In operation, the desired conditions are set up by means of those switches, and the sequence of operations of the circuits to make the exposure is initiated by a single push button.

Performance of the Oscillograph

Several factors have been discussed that make the oscillograph free from spurious

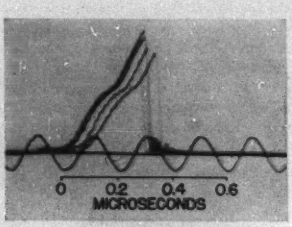


Figure 9. The consistent timing of oscillograph and generator is illustrated by 5 volt-time oscillograms of gap breakdown on one film. The variation in timing is 0.08 microsecond

deflection. Figure 7 shows a zero line and deflections due to positive and negative calibration voltages of 805 volts and 1,610 volts. This oscillogram demonstrates the accuracy and consistency of the instrument, since five separate traces were superimposed on each line without causing an appreciable increase in the width of the lines. The sensitivity was constant at 36.4 volts per millimeter for each calibration line. The 25 traces on the film have not caused fogging.

Figure 8 shows an oscillogram of a 113-megacycle oscillation in an extremely small local circuit following the breakdown of a gap. The beam crossed the film in 0.25 microsecond. The maximum writing speed on this oscillogram is about 3,000 centimeters per microsecond, which is ten per cent of the speed of light. To obtain this oscillogram, a rectangular circuit was connected directly to the deflecting plates, which provided most of the circuit capacity. The opposite side of the circuit contained a small gap that was sparked over by the impulse generator to start the oscillation. A resistor was connected in parallel with the gap to prevent deflection by voltage induced in the plate circuit previous to gap breakdown. Dividers are necessary for the measurement of high voltages and will limit the accuracy with which ultrafast transients can be recorded, rather than the writing or sweeping speeds of the oscillograph.

Comparison With Hot-Cathode Oscillograph Having Permanently Sealed Vacuum

The sealed-in high-speed oscillograph with the film outside the vacuum, on which improvements also have been reported[8,9] within recent years, occupies the position of an every-day general-purpose instrument for transient work. It is simpler in construction and operation and capably records all but the ultrafast transients for which the instrument described in this paper is especially valuable.

Conclusions

The oscillograph described should be regarded as a precision research tool capable of recording ultrafast phenomena. Due to the complexity of the circuits, the operator must use considerable care and skill to realize the best performance. The authors believe it represents marked progress in the design of ultrahigh-speed oscillographs for the measurements of transients and that several features add definitely to performance characteristics hitherto attained. During the two years in which this instrument has been in constant use, the accuracy, consistency, high writing speed, and convenience of operation have been of great benefit in the study of lightning arresters and problems of protecting insulation.

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6. Cold-Cathode Cathode-Ray Oscillograph

Application of Apparatus and Conductors Under Various Ambient-Temperature Conditions

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Synopsis: Various electrical standards are reviewed from the viewpoint of the selection and interpretation of ambient temperature values. Equivalent aging temperatures for insulation have been calculated from recorded ambient temperature data for several typical outdoor and indoor locations. From these the suitability of ambient values now used for the establishment of temperature rises for rating purposes is discussed. These values seem to be well chosen, but some clarification in meaning and in methods of using them for rating and application purposes is desirable. For apparatus rated on a 40 degrees centigrade ambient basis, appreciable margins in permissible temperature rise exist under many conditions and for many places of application. Permissible increases in loading for certain motors without exceeding conservative hot-spot temperatures are suggested, subject to the limitations imposed by other operating considerations.

Standards for Electrical Apparatus

THE permissible temperature rises for rating purposes given in various commercial standards for apparatus and conductors were obtained by considering the maximum continuous temperatures for insulation and selecting certain values of ambient temperature. The ambient values most commonly used are:

40 degrees centigrade—For commercial standards for the majority of all electrical apparatus and for some cable-rating purposes.

30 degrees centigrade—For commercial standards for wires and cables and, with qualifying statements, for the newly proposed standard for transformers.

25 degrees centigrade—For standards for rotating apparatus on electrical vehicles and in some Underwriters' regulations.

50 degrees centigrade—For standards for marine apparatus for which 40 degrees centigrade is not considered adequate.

Generally speaking, these values are well chosen for the various cases indicated, but there is some inconsistency between the wording of the standards and the methods and generally accepted theory of applying apparatus. Some standards simply specify that apparatus will have the proper rating when the temperature of the cooling medium does not exceed 40 degrees centigrade. In at least one case the statement "at no time exceeds 40 degrees centigrade" is used. In others 40 degrees centigrade is specified as the limiting ambient temperature of the cooling air or other gases, with a supplementary statement that the ambient temperature in locations where electrical apparatus is operated in the United States rarely exceeds 40 degrees centigrade. There is a general impression that 40 degrees centigrade is exceeded in only a few locations, but this is not confirmed by actual records. Weather bureau statistics show that outdoor temperatures have at times exceeded 40 degrees centigrade in 30 out of 60 stations.[3] Thus, in indoor applications, where considerable heat is generated by losses in large electrical apparatus, heat engines, steam pipes, and industrial heating equipment, 40 degrees centigrade will at times be exceeded in a large number of applications. However, the total percentage of time during which 40 degrees centigrade is exceeded is as a rule very low, not more than 0.5 per cent for most outdoor locations and a somewhat higher percentage for some indoor locations. Nevertheless, with a strict interpretation of the statement that the cooling medium must not exceed 40 degrees centigrade, a large percentage of applications would have to be considered as special. In actual practice, standard apparatus having a temperature-rise rating based on a 40 degrees centigrade ambient is actually applied more or less indiscriminately with success in all but unusually hot locations. This is to be expected in the light of various investigations on the life of insulation, which have shown conclusively that life or rate of deterioration is dependent upon both time and temperature.

Since the temperature-rise rating presumes continuous operation at the standard ambient temperature, it may be expected that satisfactory life of insulation at rated load will be obtained when this ambient temperature is maintained continuously. If this is true, it follows directly from these investigations on the life of insulation that equal life will be obtained in spite of short periods at temperatures above 40 degrees centigrade, if values below 40 degrees prevail for the greater part of the time. This is the condition found nearly everywhere in practice; ambient temperatures usually vary over wide ranges and include values below 40 degrees centigrade for most of the time.

On the basis that a continuous ambient is used for rating purposes, it is merely necessary to make sure that the prevailing ambient temperatures, which vary continually in practice, are equivalent in their aging effects to this standard value. This will result in the most effective application of apparatus. A method of determining the aging temperature equivalent to any given varying temperature is available in the eight degrees centigrade rule,[1,2] which states that the aging effect of temperature doubles for each eight degrees increase in temperature. This eight degrees centigrade rule is not a precise law and cannot be applied indiscriminately for all insulation, but it does serve as a useful guide for analytical purposes.

Equivalent Aging Temperatures

The use of the eight degrees centigrade rule is illustrated in Figure 1. Curve *A* was obtained from available outdoor temperature records for Dallas, Tex. It shows the percentage of time during which certain temperature values were exceeded. To obtain corresponding machine temperatures, the hot-spot temperature rise

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of 65 degrees centigrade permissible for many forms of class-*A* insulation is added to curve *A*, giving curve *B*. By using the eight degrees centigrade rule, it is possible to calculate a constant temperature *D* (appendix II) which has the same effect in deteriorating insulation as curve *B*. By subtracting 65 degrees centigrade from *D*, the value *C* is obtained. This is a single value equivalent to the ambient temperature curve *A*. The validity of this operation depends, of course, on the empirical eight degrees centigrade rule, but its application is conservative. It is assumed that the insulation temperature follows changes in ambient temperature exactly. Actually, insulation temperatures lag and the effect of the higher ambient temperatures is somewhat less than curve *B* indicates.

Dallas is one of the hottest places in the country. Although the maximum temperature exceeds 40 degrees centigrade, the equivalent yearly outdoor temperature is only 22 degrees. Figure 2 shows

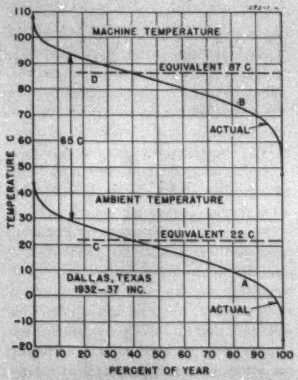

Figure 1. Actual and equivalent ambient and machine temperatures for outdoor locations in Dallas, Tex., 1932–37 inclusive

curves and values for other locations and the equivalent temperatures are from 12 to 22 degrees centigrade. Therefore, outdoor apparatus can be safely applied almost anywhere if the standard temperature rises are based on an ambient of 25 degrees centigrade. However, a further assumption that heat from sun radiation can be neglected is necessary. It has been shown that this assumption is correct in most cases, because wind velocities nearly always existing outdoors, though rather low, compensate for sun radiation. There are a few exceptions to this, such as meters or transformers mounted in well-protected corners of buildings and subject to considerable sun exposure, the influence of which may then at times be appreciable.

Most types of electrical apparatus are at times located indoors and the consideration of outdoor temperatures is in itself of restricted value. However, it is useful as a basis for the study of indoor temperatures for which no comprehensive statistics are available or likely to be available in the near future. Therefore, a logical method is to use outdoor statistics and make tests on the differences between outdoor and indoor temperatures for a limited number of typical indoor locations.

In buildings heated for human comfort, a more or less constant temperature is maintained during the cooler seasons of the year. A constant value of 25 degrees centigrade represents the higher limit of temperatures prevailing during the heating period. At other times it might be assumed that the indoor temperature can be maintained the same as the outdoor temperature in a substantial ideally ventilated building. In practice there are, however, a number of factors tending to increase indoor temperatures even when no appreciable amounts of heat are generated inside. These factors are: heat from occupants and lighting fixtures, the poor heat exchange generally given by open windows, the fact that windows are kept closed a part or all of the time, and, finally, heat caused by sun radiation.

Figure 3 shows simultaneous outdoor and indoor records taken in an office in a substantially built modern office building having northwestern exposure with sun radiation through the windows only after 5 p.m. At the end of the office hours, about 5 p.m., the windows are closed and night temperatures are appreciably higher indoors. During the second day shown it was cloudy after 5 o'clock, and the maximum temperature was only slightly higher indoors. In contrast, the marked influence of the late afternoon sun appeared during the third day, resulting in a difference of 5.6 degrees centigrade (ten degrees Fahrenheit) at 6:30 p.m. Similarly the influence of sun exposure with closed windows, as may be found in unoccupied storerooms and similar places with southern exposure, can be appreciable. The high peak on the first day indicated in Figure 3 was caused by the recording instrument being directly exposed to the sun. The effect is quite marked, although the instrument case is light in color and ventilated. If apparatus with dark heat-absorbing surfaces is subjected to sun radiation through windows, the effect may be quite marked because of the lack of compensating outdoor breezes.

Similar records have been obtained in a powerhouse basement and a factory building. The powerhouse basement was without windows and poorly ventilated, but the recorder was at least ten feet from direct heat sources such as steam pipes. The factory building was a single-story structure, with a covering of boards plus sheet iron on the walls and paper on the roof. Several small ovens operating at temperatures up to 175 degrees centigrade were located in the vicinity of the thermometer. It was placed near the south windows as well, which resulted in considerable influence from sun radiation.

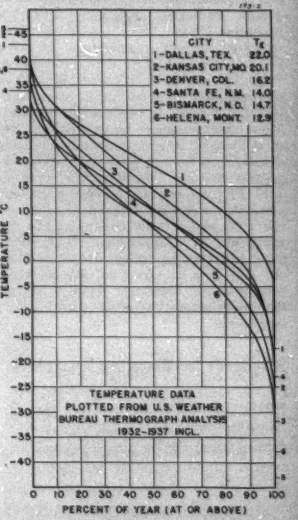

Figure 2. Actual and equivalent outdoor ambient temperatures for six cities of the United States

From these tests the curves of Figure 4 have been estimated for certain indoor conditions and the equivalent ambient temperatures calculated. The tests covered only a 100-day period in midsummer, but the data have been adjusted to an annual basis compared to the outdoor curve for the period of test and then applied to the Dallas outdoor curve. A constant indoor temperature of 25 degrees centigrade has been assumed when lower temperatures prevailed outdoors. Figure 5 shows the same procedure applied to the outdoor curve above 25 degrees centigrade for Bismarck, N. D. This is one of the hotter locations in the northern section of the United States, as divided in Figure 2 of AIEE Standard No. 1.[3] Although maximum temperatures are high, they do not persist as in more southern climates, and

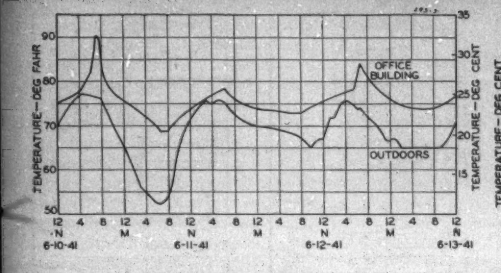

Figure 3. Recorded temperatures outdoors and in a modern office building at East Pittsburgh

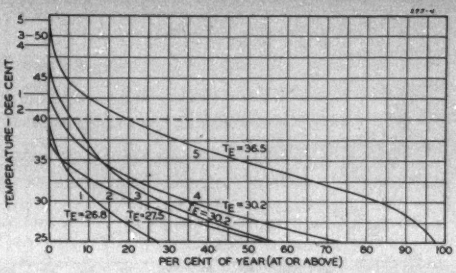

Figure 4. Estimated prevailing and equivalent ambient temperatures for typical locations in Dallas, Tex.

1. Outdoors 1932–37 inclusive—above 25 degrees centigrade
2. Office building—northern exposure—open windows daytimes
3. Office building—southern exposure—closed windows
4. Building with industrial heat sources—thin walls
5. Powerhouse—poorly ventilated area

equivalent aging temperatures are correspondingly lower than in Dallas. The equivalent aging temperatures for these selected locations in Dallas and Bismarck lie between 25 and 32 degrees centigrade for the most part, with the Dallas powerhouse 36.5 degrees centigrade. In the latter case, even with a 25 degrees centigrade minimum temperature, 30 degrees exceeded most of the time, and 40 degrees exceeded 20 per cent of the time, the equivalent temperature is still well within the 40-degree standard. In practice all sorts of variations will be encountered in individual applications, but for either locality it seems that, regardless of high maximum temperatures, equivalent aging temperatures as high as 40 degrees centigrade are likely to be found only under very unusual circumstances. Since Dallas is one of the hotter places in the country this statement may be applied to apparatus locations in buildings generally.

Figure 5 seems to indicate that, except with a great deal of heat generated and poor ventilation, the equivalent aging temperature will rarely exceed 27 degrees centigrade for large sections of the country. This applies particularly to many highly industrialized sections of the United States. Moreover, the 27 degrees centigrade value is based on the assumption that indoor winter temperatures are 25 degrees. Actually, the temperatures maintained in industrial establishments in winter are nearer 20 degrees centigrade, which results in equivalent aging temperatures for the year certainly no greater than 25 degrees.

Enclosures and Buildings

The inside temperatures of enclosures provided for the specific purpose of housing electrical apparatus are usually higher than the outside. In relatively small enclosures with restricted ventilation, such as steel cubicles for switch-gear, a distinction is made between inside and outside ambient temperatures. Extreme differences have of course been encountered when the enclosure had no ventilation. These conditions require special consideration in each case. On the other hand, when apparatus is enclosed in a regular building, the temperature in the building is considered the ambient temperature for the apparatus.

In this connection some interesting tests have been reported on an indoor transformer installation.[4] A ventilated building about 18 by 25 feet and 24 feet high housed three power transformers. In Figure 6 the heaviest lines represent the outline of the building, with cooling air flow indicated by the arrows. Figure 6a shows isothermal lines midway between two transformers, and Figure 6b shows the isothermal lines for a section through the center line of a transformer. The numbers given on the lines indicate the difference between outside and inside temperatures. The average temperature in the building is about eight degrees centigrade above the outdoor temperature. In the case of Dallas this would give an equivalent temperature of about 30 degrees centigrade. However, the lines above the transformer show an excess of 11 to 15 degrees centigrade over outside temperature. Applied to the Dallas equivalent temperature of 22 degrees centigrade, this gives ambient values of 33 to 37 degrees. If auxiliary apparatus were installed above the transformers, it would be operating under these ambient conditions. This conclusion is made under the assumption that the building is fully ventilated at all times; however, the ventilation may be restricted in cooler seasons of the year, resulting in equivalent ambient temperatures of 35 to 40 degrees centigrade at points above the transformers. It is believed that this general situation is frequently found in buildings housing electrical apparatus.

A somewhat different case is an industrial building subject to considerable sun radiation or other heat sources. Temperatures in the upper regions of the building, where some types of apparatus may be installed, may be appreciably higher than in the lower parts where temperatures usually are measured. Although some of the previous cases derived from tests do not show equivalent ambient temperatures in excess of 35 degrees centigrade, equivalent temperatures close to 40 degrees may be expected in some parts of many buildings. The short-time maximum temperature in such locations is likely to be 50 to 60 degrees centigrade.

Preferred Standard Ambient Temperatures

From these studies, the suitability of the ambient temperature values used for temperature-rise standardization purposes can be considered. For maximum simplicity in the application of apparatus, the ambient temperature of 40 degrees centigrade has been well chosen. The temperature conditions for the very small percentage of cases where apparatus so standardized cannot be safely applied are so unusual that they will be readily recognized. (An equivalent temperature of 40 degrees centigrade usually permits occasional maximum values of 50 to 60 degrees; consequently, misapplications are easily avoided.)

On the other hand, it might be contended that 40 degrees centigrade is contrary to maximum economy, because in a large percentage of applications equivalent ambient values of 30 to 35 degrees are not exceeded. The question of what would be gained by using 35 degrees centigrade as a

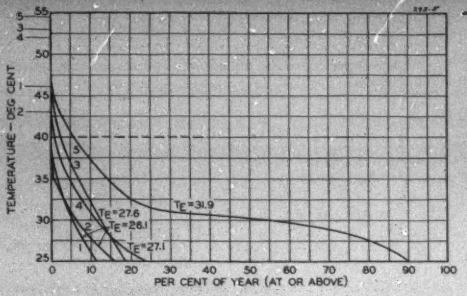

Figure 5. Estimated prevailing and equivalent ambient temperatures for typical locations in Bismarck, N. D.

1. Outdoors 1932–37 inclusive—above 25 degrees centigrade
2. Office building—northern exposure—open windows daytimes
3. Office building—southern exposure—closed windows
4. Building with industrial heat sources—thin walls
5. Powerhouse—Poorly ventilated area

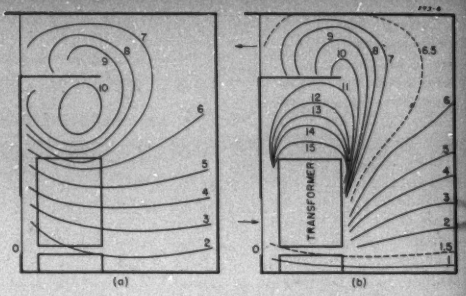

Figure 6. Isothermal lines around a large transformer in a ventilated enclosure

(*a*) Between two transformer units
(*b*) About the center line of one unit

basic ambient value might therefore arise. It would permit hot-spot temperature rises[3] of 70 instead of 65 degrees centigrade for class-*A* insulation, and 95 instead of 90 degrees for class-*B* insulation, gains of 7.7 and 5.6 per cent respectively. With apparatus having chiefly copper losses, this means increases in rating of only 3.9 and 2.8 per cent respectively; with apparatus having both iron and copper losses, gains of 7 and 5 per cent might be realized.

For these gains it seems wrong to sacrifice the present satisfactory situation which permits almost indiscriminate application of standard apparatus drawn from storerooms all over the country. A great deal of this apparatus has line-voltage magnet coils, and adjustment of the load to suit special ambient temperature conditions is not possible; the same is true with motors permanently built into or connected to driven machines. In these cases special apparatus would be required, if the temperature rating of standard apparatus were not based on a sufficiently high and universally applicable ambient temperature. The cost probably would more than balance any economic gain from a lower ambient as a basis for standard apparatus. It is of course possible to load certain machines somewhat below their normal rating, if the ambient temperature is higher than that used as a basis for the rating; however, it is just as easy to apply a machine to a somewhat higher load, if its rating is based on 40 degrees centigrade, and it is used in a locality with a lower equivalent ambient value.

Considering further that there are certain inaccuracies in the eight degrees centigrade rule used as a basis for this study, and that there is usually not much known about the temperature conditions for many applications, it certainly seems advisable to retain the margin of safety and the simplicity afforded by the use of 40 degrees centigrade as an ambient value for general purposes. A further reason for adhering to this value is that frequently apparatus is installed under conditions which interfere with proper ventilation.

In Figure 7, curve *A* has been estimated to show the percentage of all apparatus that can be applied without special consideration for temperature-rise ratings based on different standard ambient temperatures. In the absence of extensive statistical data no claims can be made for the accuracy of the curve. It does illustrate the basic considerations involved and the greater applicability of stock apparatus, the higher the standard ambient temperature on which ratings are based.

In spite of the advantage of the 40 degrees centigrade value for general use, it must be admitted that the use of lower values such as 30, or even 25 degrees, is justified where some conditions of application or economic considerations apply. One such case is rubber-insulated wire, some varieties of which are suitable for a continuous maximum temperature of only 50 degrees centigrade. The permissible rise is 20 degrees centigrade with an ambient temperature of 30 degrees, and only 10 degrees with an ambient of 40 degrees; in other words, the increase of rating possible with 30 degrees is 41 per cent. The greater part of this wire is used in places where an equivalent temperature of 30 degrees centigrade is not exceeded. This is roughly illustrated by curve *B* of Figure 7. (The eight degree centigrade rule may not apply to rubber-insulated wire, and curve *B* may not be quantitatively correct.) It follows that the sacrifice in economy resulting from an ambient of 40 degrees centigrade for this wire is entirely too great for the advantages gained thereby. This is especially true, because in the few locations where higher temperatures prevail, standard wire can be used merely by reducing the rating. Hence, the storeroom problem, which would complicate the situation in connection with many other types of apparatus, is of no particular importance. On the whole, it seems that ratings for rubber-covered wire based on a standard ambient of 30 degrees centigrade are well justified.

Another case of interest is that of transformers. Curve *C* has been estimated as applying to transformers and shows approximately the percentage of transformers which can be applied on a 30-degree centigrade basis; this percentage is high because most transformers are located outside. A rather small percentage of 30 degrees centigrade transformers require special consideration in their application. Also, since transformers are nearly always applied by engineers fully familiar with all the problems involved, ratings based on a 30 degrees centigrade ambient seem well justified. (The proposed transformer standards specify that nominal rating can be used if the average temperature during any 24 hours does not exceed 30 degrees centigrade, with a maximum of 40 degrees, which gives a continuous hot-spot temperature of 95 degrees. This provision in itself will result in an equivalent value somewhat in excess of 30 degrees centigrade for the 24-hour period, as here developed. However, since there will be only a few days during the year with such high temperatures, it is estimated that the provisions in the transformer standards are about the same as an equivalent temperature of 30 degrees centigrade or less.)

Curve *D* applies to rotating apparatus for electric vehicles. In view of the necessity to keep weight to a minimum, and because such apparatus is nearly always outdoors, the present practice of a 25 degree centigrade standard ambient is justified. For the sake of maximum simplicity in the standard structure, a value of 30 degrees centigrade for railway work seems preferable and would hardly interfere with maximum economy. The five degree centigrade difference represents a very small percentage of the customary temperature rises in this type of apparatus.

There are other cases where a standard ambient temperature of 30 degrees centigrade would be justified. For example, some domestic or office appliances are used almost exclusively in locations where an equivalent temperature of 30 degrees centigrade is not exceeded while the devices are in use. There are practically no homes or offices in which the equivalent temperature exceeds 30 degrees centigrade while occupied. Even if higher temperatures prevail when windows are closed, this is of no particular importance because the devices are not then loaded and will not overheat.

Therefore, considering both simplicity and economy, it seems well to retain the 40 degrees centigrade value but to recognize that a 30-degree value is justified for some apparatus and applications. It will of course also be necessary to use the 50 degree centigrade value for those few locations, such as holds of ships, where 40 degrees is not sufficient. An even higher standard ambient value may be necessary in special cases.

The previous considerations all are based on the deterioration of the conventional insulating materials, with the idea of assuring satisfactory life of apparatus from that point of view. The influence of temperature conditions on the oxidation and operation of contact surfaces or upon the operation of electronic devices and other types of apparatus may, of course, be subject to different laws and thus require separate consideration. Very few quantitative data seem to be available for such studies, but AIEE standards coordinating committee 7 is working on these problems. Regardless of the results, it would seem best to use the same basic ambient values for standardization purposes, with the understanding that satisfactory results are obtained if these ambient temperatures are maintained continuously. Any difference between the characteristics of other types of apparatus and ordinary electromagnetic apparatus can be taken care of in the methods of application.

Conclusions

Ambient temperature values equivalent to the continually changing temperatures encountered in practice have been derived for various localities. From these data it is concluded that the standard ambient temperature values selected for use in establishing temperature rises for rating purposes in the various standards are, in general, sound. It is suggested, however, that some clarification in meaning and in methods of using these selected values for rating purposes is desirable.

The data also show that for apparatus rated on a continuous 40 degree centigrade ambient basis, certain margins in temperature rise exist under many conditions and for many places of application. Recognition of this situation is particularly valuable at this time, when it is often necessary to increase loads on industrial equipment. Under these rating conditions an equivalent ambient temperature of 25 degrees centigrade may permit overloads which increase operating temperature-rises by 15 degrees without exceeding permissible hot-spot temperatures, when this is compatible with other operating considerations.

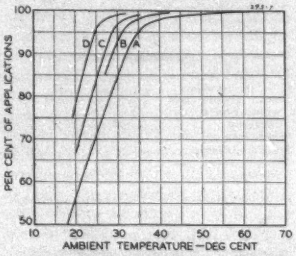

Figure 7. Estimated curves for different apparatus applications, showing the percentage of applications for which standard apparatus based on different ambient temperatures is suitable

A. General
B. Cables
C. Transformers
D. Railway apparatus

Apparatus ratings primarily are based on a continuous hot-spot temperature of 105 degrees centigrade for class-*A* insulation, although transformer standards specify 95 degrees. At times doubt has been expressed that the 105 degrees centigrade temperature will give satisfactory life of insulation, since laboratory tests have demonstrated loss in mechanical strength of materials continuously subjected to 105 degrees. On the other hand, hot spots in many machines occur in slots where the insulation is well supported and where some loss of mechanical strength can be tolerated. Extensive trials on actual machines at 105 degrees centigrade for long periods have shown very satisfactory life.

To eliminate this doubtful point, it can be assumed that the equivalent hot-spot temperature should not exceed 100 degrees centigrade. This takes advantage of only ten of the 15-degree margin and gives a permissible temperature-rise of 75 instead of 65 degrees, or an increase of 15.4 per cent. For general-purpose motors based on a 40 degree centigrade temperature-rise by thermometer, an extra ten degrees is available, permitting an increase in this case of 36.5 per cent. (Actually, the service factor for these machines requires the ability to carry a 15 per-cent overload with a 40 degree centigrade ambient maintained continuously.) Table I shows permissible increases in loads for motors, considering temperature only and taking advantage of these temperature-rise increases of 36.5 and 15.4 per cent. With the total losses increased by these percentages, permissible increases in copper losses are given in columns 3 and 5. Columns 4 and 6 show the increases in currents corresponding to these copper losses.

Table I. Permissible Per-Cent Increases in Motor Losses and Currents for 100C Hot-Spot Temperatures at 25C Ambient

Assumed Loss Distribution		General Purpose 40C Rise by Thermometer		Ratings Based on 50C Rise by Thermometer	
		Copper		Copper	
Iron	Copper	Loss	Current	Loss	Current
0.25	0.75	49	22	20.5	10
0.35	0.65	56	25	25.5	12
0.50	0.50	73	31.5	31	14.5

Since hot-spot temperatures are not directly proportional to total losses but depend also upon distribution of losses between copper and iron, these figures may be somewhat optimistic. It does appear reasonably safe, however, to increase currents on 50-degree-rise machines by 8 to 13 per cent and on general-purpose 40-degree-rise machines by 20 to 30 per cent under the conditions stated. For induction motors torque usually increases somewhat faster than the current. It is assumed, of course, that operation is at rated voltage. If operation is not at rated voltage, part of the margin indicated may not be available for increased loads.

Furthermore, this paper deals only with the effect of temperature on the aging of electrical insulation. There are other factors that should be considered when con-

templating placing an overload upon a rotating machine.[9] Mechanical strength of shafts, bearings and couplings, commutators, lubrication, and so forth, must be recognized as limiting factors also and should receive due consideration. Furthermore, utilizing these temperature margins may reduce insulation life from that commonly obtained under operation at substandard temperatures.

Unfortunately, simple conclusions covering all conditions encountered in practice are not possible, but it is hoped the data presented will be of assistance in determining increased loads for existing machines and apparatus in this time of emergency. Also, the statistical data of AIEE Standard No. 1 should be helpful in determining the localities where prevailing ambient temperatures might make increased loading of equipment possible.

Although the data given here are primarily intended to be helpful under present emergency conditions, it is also hoped that the views presented will be convincing evidence of the futility of suggestions for the use of a great variety of ambient temperature values and departures from standard temperature-rises in commercial transactions. Certain variations in ambient temperatures always will occur but wide confusion would result from attempts to reflect these into the system of rating apparatus.

Appendix I. Ambient Temperature Specifications in Standards

(The wording referring to ambient temperature in the different standards is far from uniform. The letters in these data indicate certain general classifications but do not cover all the variations in wording even where no distinctions in meaning are intended. Furthermore, where apparatus may be water-cooled, supplementary statements are given.)

	50C	40C	30C	25C	24C
AIEE and American Standards Association					
Metal-tank mercury-arc rectifiers					A
Industrial control apparatus					B
Electric-railway control apparatus					B
Capacitors					B
Apparatus bushings					C
Air switches and bus supports					B
Relays associated with power switchgear					A
Protector tubes					A
Fuses above 600 volts					B
Automatic stations					B
Switchboards and switching equipment					B
Switchgear assemblies					A
Lightning arresters					A
Electric-arc-welding apparatus					B
Resistance welding apparatus					B
Electrical installations on shipboard				A	—
Railway motors			—	—	B
A-c power circuit breakers					B
Rotating electrical machinery					B
Transformers, regulators, and reactors					D
National Electrical Manufacturers' Association					
Industrial control					B
Motors and generators					A
Oil circuit breakers					E
Signalling transformers			—	—	F
General-purpose specialty transformers					E
Underwriters Laboratories					
Industrial control					A
Motor-operated fans			—	—	C
Branch circuit and service circuit breakers			—	—	H
Service cables			—	—	F
Auxiliary breakers					I
Motor-operated appliances					G
Insulated Power Cable Engineers Association					
Cables					A
National Electrical Code					
Conductors			—		J

General Classification

A. Equipment conforming with these standards shall be suitable for carrying the rated load when and where the ambient air temperature at the equipment does not exceed ——C.

B. Apparatus conforming with these standards shall be suitable for operation at the standard rating when and where the temperature of the cooling medium does not exceed ——C.

C. Apparatus bushings conforming to these standards shall be suitable for operation at their standard ratings when and where the temperature of the external cooling medium does not exceed 40C maximum or 30C average for any 24-hour period.

D. Apparatus conforming to these standards shall be suitable for operation at rated load with rated secondary voltage, provided the temperature of the cooling air at no time exceeds 40C, and the average temperature of the cooling air during any 24-hour period does not exceed 30C.

E. The standard ambient temperature of reference when the cooling medium is air shall be 40C.

F. The standard ambient temperature shall be 24C.

G. It is assumed that the ambient temperature will be ordinarily about ——C.

H. The temperatures given in these requirements are based on a room temperature of 25C.

I. The tests shall be conducted with the switch at room temperature, preferably 24C.

J. Capacities are based on room temperature of 30C.

Appendix II. Calculation of Equivalent Aging Temperature by Eight Degree Centigrade Rule

The continuous temperature equivalent to a given temperature distribution curve for a period of time is calculated by dividing the curve into convenient trapezoids or rectangles and applying equations 1 and 2.

$$A = t_0 \frac{(e^{KT_2} - e^{KT_1})}{K(T_2 - T_1)} \quad \text{for a trapezoid} \qquad (1)$$

$$A = te^{KT} \quad \text{for a rectangle} \qquad (2)$$

A = aging units

t_0 = time in convenient units (hours or per cent)

$e = 2.718 \qquad K = 0.0865$

T_2 = maximum temperature of trapezoid in degrees centigrade

T_1 = minimum temperature of trapezoid in degrees centigrade

T = constant temperature of rectangle in degrees centigrade

The aging units for all the sections of the curve are added, and equation 2 is applied to this sum for the total time involved. Solving for T gives the equivalent aging temperature for the curve.

With $K = 0.0865$ the aging units are doubled for an eight degrees centigrade increase in temperature.

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Effect of Lightning on Thin Metal Surfaces

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Synopsis: In the search for means for measuring the properties of natural lightning much can be learned from the evidence left at points struck by lightning. This paper deals principally with such evidence and the process of evaluating the characteristics of the lightning strokes responsible for the evidence.

For six years a nickel-plated, 18-inch copper sphere, 878 feet above the ground atop the WSM radiator at Nashville, had been collecting data in the form of holes and pits due to lightning strokes to the sphere. A total of 150 holes of varying sizes were found together with 300 pits. A laboratory setup was made consisting of the high-capacity impulse generator together with a d-c generator so arranged that the known characteristics of lightning with respect to the so-called continuing current could be duplicated. With this equipment holes having the same appearance could be produced in copper sheets, and from the results of the test a calibration curve was produced. At the same time calibration curves were obtained for other metals in addition to copper. From these data an expectancy curve was obtained between coulombs and per cent of holes. The average hole corresponded to 15 coulombs while the maximum size hole corresponded to 240 coulombs.

No satisfactory calibration was obtained for the pits, many of which no doubt were the result of high current peaks having a low coulomb content.

It is interesting to learn that of the 150 holes in the sphere 89 were found in the upper half and 61 in the lower half, with the great majority appearing in a six-inch belt around the seam at the sphere's equator.

The results of some laboratory high-current impulses on metal sheets are also shown, indicating pressure effects without appreciable burning.

A lightning stroke to a metal-roofed rural home is described, the largest hole in the roof indicating a charge of 210 coulombs. The home was not wired, but a part of the lightning discharge traveled a distance of 162 feet to the wired house next door to puncture the cellar wall and contact the neutral ground rod driven in the cellar. Another channel was found extending to the base of the service pole where two ground rods were driven. It was estimated that the discharge removed approximately 250 cubic feet of earth in its travel. Available data indicate the stroke was negative and had a total charge of more than 240 coulombs with a suggested peak current of the order of 200,000 amperes. Although the struck home was quite badly damaged, there was no fire, nor was there any trouble with the electric equipment in the wired home.

The results of this work indicate that sheet metal may be made to yield certain data of value with reference to lightning.

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LIGHTNING strokes to objects on the earth have been characterized by two major effects[1-4] one causing explosive effects[5,6] and the other often resulting in fire. In many cases both effects have been present. The explosive effects are now known to be due to sudden increases in current which may reach a crest of several thousand or even a hundred thousand amperes or more in a few millionths of a second, decaying to half of the crest value in a time of the order of 40 microseconds. It is the expansion effects in the air resulting from these rapid current changes which cause the thunder which we hear. The burning effects are the result of the flow of current of relatively low magnitude of the general order of 200 or 300 amperes[7] for times which may be as long as 1.5 seconds, but on the average, persist for about 0.3 second or about 7,000 times as long as the average time to half value of the current peak. Correlating photographic and oscillographic data for strokes to the Empire State building having a height of 1,275 feet, strokes began at the building in about 80 per cent of the cases. As the height of the earth object becomes less, the percentage of cloud-initiated strokes increases. It is believed that for transmission-line heights the contacting strokes are always cloud initiated. Currents in earth-initiated strokes measured at the earth end begin with a relatively small value of current—a few hundred amperes—which develop into a continuing current when contact is made with the cloud. Superimposed current peaks may develop later, with varying time intervals and magnitudes, all of these peaks being cloud-initiated just as in the case of the stroke to objects of ordinary height on the earth's surface.

Laboratory Lightning

The impulsive nature of lightning strokes has been known for a long time, and it was natural to consider the cloud as one pole of a condenser and the earth as the other. Thus the laboratory lightning maker noted the similarity between the discharge of a charged laboratory capacitor and natural lightning. It looked the same, and the sound effects were there also. Furthermore, wood could be blown apart as in nature, and many of the distance–time–voltage or current phenomena found in connection with the operation of outdoor circuits could be reproduced. And so with the development of the Marx-circuit impulse generator and the cathode-ray oscillograph, data became available proving the similitude of the laboratory and the natural lightning as to the nature of the phenomena involved.

The continuing part of the natural lightning stroke was not simulated, as its existence was not shown oscillographically until 1937. The lack of knowledge of this component explains the inability of investigators to make the lightning fulgurites found in nature when discharging a lightning generator into wet sand. The impulsive nature of the current blew the

Figure 1. Circuit to control duration and amplitude of long-duration low-current discharges, preceded by impulse current

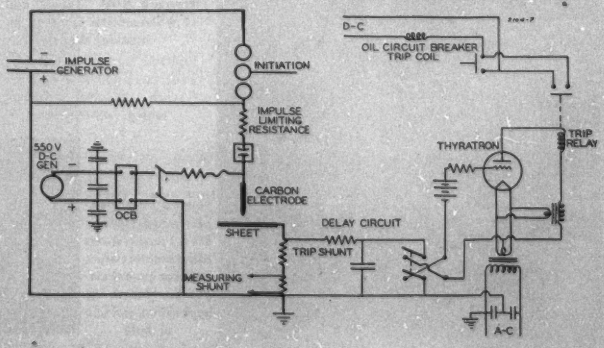


Figure 2. Side view of lightning-damaged 18-inch nickel-plated copper sphere installed for six years at top of WSM vertical radiator 878 feet above ground

sand out of the container, and it was not until currents of a few amperes were used, continuing for a second or so, that fulgurites could be formed.

The charge represented by the current peak is very small indeed. The average measured in natural lightning is only a fraction of a coulomb, whereas the charge represented by the continuing current may be of the order of 200 coulombs or more. Even very large impulse generators with voltages suitable for general testing work will have a charge of considerably less than ten coulombs. It is clear, therefore, that to simulate the complete lightning stroke a generator of more than 20 times the present capacity is needed, and therefore it is necessary as an economic expedient to make use of generators such as illustrated in Figure 1, where the discharge is initiated by a high capacitance generator, with a follow current supplied by a 500-volt d-c generator. Such an arrangement, though not suitable for long arcs, was quite satisfactory for the tests on metal sheets described in this paper. Modifications of this circuit have been used during other long-duration lightning current tests. More than one high current impulse may be superimposed using a circuit of this general character.

Lightning Strokes to Sphere at WSM

Our interest in the use of thin metal as a means of collecting lightning data was aroused when William Montgomery, Jr., engineer for WSM radio station of the National Life and Accident Insurance Company at Nashville, Tenn., sent us the sphere illustrated in Figure 2. This nickel-plated, 18-inch diameter sphere made of 19-mil copper had been in service at the top of WSM's vertical radiator, 878 feet in height, for a period of six years. During that time it was struck frequently by lightning and in the summer of 1937 was thrown to the ground during a lightning storm which damaged the tuning coil at the base of the tower as shown in Figure 3. The sphere was damaged in its fall on the reverse side but had been mounted in the position shown in Figure 2.

The large number and varying size of holes and pits found indicated that the sphere could be made to tell a story about lightning strokes if a proper calibration for the holes could be found. The globules of copper found around many of the holes indicated clearly that the holes were produced by continuing currents rather than by current peaks, which would have produced sufficient pressure in many cases to have blown the molten metal away.

Tests were begun, therefore, with the circuit shown in Figure 1, using a variety of current and time values until the appearance of the holes produced corresponded closely to those found on the WSM sphere. A few of the test holes are reproduced in Figure 4. A calibration curve is shown in Figure 5 together with a similar curve for galvanized iron. All tests were made with the sheet positive, electrode negative.

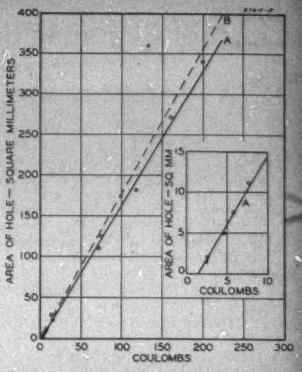


Figure 5. Relation between coulombs in the arc and resultant area of holes burned in (A) 15-mil galvanized iron sheets, (B) 20-mil copper sheets

Sheet positive, electrode negative polarity

Using the calibration curve of Figure 5 for nickel-plated copper sheets, the experience curve for the entire sphere in terms of coulombs versus holes was obtained and is compared, in Figure 6, with the curve of strokes versus coulombs as obtained for the Empire State building. Considering the fact that the number of holes per stroke is not known in the case of the WSM sphere, the agreement seems quite good when it is remembered that in many cases there may be more than one hole per stroke. The Empire State building data come from measurements of oscillograms and are known to represent the complete stroke. Of course, the difference in height and location no doubt has also had some effect on the recorded results.

It is a matter of considerable interest to note the number of holes in the sphere below its equator compared with those above. A curve similar to that of Figure

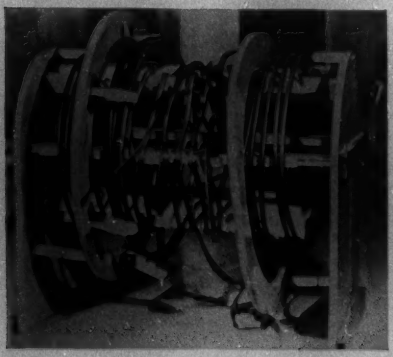


Figure 3 (left). Tuning coil of WSM radiator damaged by lightning stroke

Probable current crest 66,000 amperes—positive polarity. 3/8-inch (outside diameter) tubing. 40-mil wall

Figure 4 (right). Samples from d-c tests on 20-mil copper sheets to determine relation between current amplitude, length of application, and size of hole

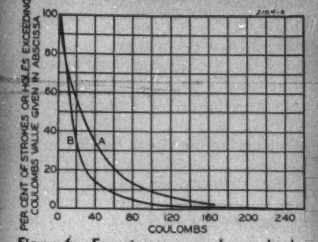


Figure 6. Expectancy curves for coulombs conducted in lightning strokes

A—Oscillographic measurement Empire State building

B—Hole calibration for WSM sphere

6 for the upper and lower halves shows ten coulombs at the 80 per cent point for the upper half and five coulombs for the lower, while for values below 50 per cent the curve for the upper and lower halves is about equal to and practically coincides with that shown in Figure 5 for the whole sphere. The total number of holes in the upper half is 89 and in the lower is 61. Within a three-inch belt above the equator, 44 holes were found, while in a similar zone below the equator, 41 holes were counted, with five holes in the seam around the equator. Thus, 60 per cent of the holes were located on 32 per cent of the total surface of the sphere. In view of the distance to the cloud, the field surrounding the sphere is quite uniform except for the effect of its support which would lead one to expect a shielded zone near the point of attachment, and this is just what was found. If the strokes represented by the holes were all initiated by the tower, one would expect streamers to be formed as the cloud field became more intense from all over the sphere's surface except close to the point of support. Chance conditions of ionization in the atmosphere probably have considerable effect in determining which of the streamers from the sphere will develop into the stroke.

It is quite likely also that the seam around the equator had a considerable effect in promoting the formation of streamers at the time of a stroke. Drops of rain water, particularly at the seam may have added to this effect. The top of the sphere was apparently shielded to some extent by a probable extension of the sphere support above the top of the sphere. The details of the attachment are not known.

Figure 8. 265,000-ampere negative-polarity discharge through 10-mil plain copper sheet

Side away from arc. Sheet used as one electrode

Figure 10. Exterior view of Amherst house struck by lightning

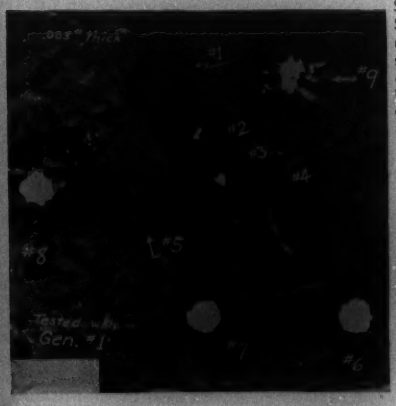
(*A*) Position of chimney. (*B*) Location of large hole. (*C*) Location of several small holes

Three hundred pits were found, many of these being accounted for as direct strokes having relatively high current magnitude, but having a low coulomb content (two coulombs or less). It does not appear to be possible to draw any definite conclusion concerning these pits in terms of current magnitude. It is possible, of course, that some of them are part of strokes which burned holes, and, if so, the effect on the calibration of holes in terms of strokes would be small on account of the small coulomb content.

In considering the interpretation to be put upon the results obtained by this sphere, it should be recorded that the number of separate strokes is not known, although Mr. Montgomery believes, based

Figure 7 (left below). 40,000-ampere negative-polarity discharge through five-mil nickel-plated copper sheet

Side-facing arc. Small holes or burns numbers 1 to 5, sheet used as one electrode. Large holes numbers 6 to 9, sheet mounted between electrodes



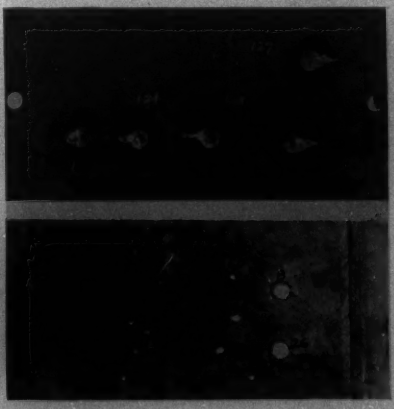


Figure 9 (right). Holes burned by relatively low-current long-time laboratory discharges.

Top, 3/8-inch steel plate. Bottom, 0.015-inch galvanized tin. Side facing electrode

Figure 11. Damage to cement basement wall of A. T. Rouleau house, August 4, 1939, caused by lightning which came in across ground surface from nearby Joslyn house which was struck directly

Pelham Road near Amherst, Mass.

on his records, that 24 direct hits is a reasonable number to use. It is probable that this number is too low. With 150 holes, and assuming equal distribution of holes for all strokes, one arrives at seven holes per stroke which, from Figure 6, would indicate an average coulomb value of $7 \times 14 = 98$ coulombs, which is probably much too high, although the maximum hole indicates 240 coulombs. It must also be recognized that more than one stroke could contribute to the same hole as well as the same stroke making several holes.

At WSM, magnetic links had been installed on the antenna lead-in and guy wires at the time the sphere came down and the tuning coil of Figure 3 was damaged, which indicated a current of +66,000 amperes in the antenna lead-in and +6,400 amperes in two of the guy wires and a total of −73,000 amperes in six other guy wires. This record may cover more than one stroke, but it does indicate the highest currents recorded. It is interesting to point out that the most severe current peak measured with the cathode-ray oscillograph at the Empire State building[7] had a crest current of 58,000 amperes, contained 4.9 coulombs to half current value, and was positive.

Tests made in the laboratory on tubing similar to that of the tuning coil shown in Figure 3 indicate that the turns of the coil begin to pull together at a current crest of 75,000 amperes. The copper tubing itself begins to flatten at around 118,000 amperes. The difference between the effects of laboratory current amplitudes and the 66,000 amperes measured in the actual stroke is probably due to different wave shape, as well as the fact that two concentric coils were involved in the actual stroke. Furthermore, the heavy discharge current may have been preceded by a high coulomb–long duration discharge heating the copper tubing sufficiently to produce crushing at much lower crest currents. The laboratory current waves were oscillatory waves of 86 microseconds period with the initial peak of negative polarity. The tuning coil consisted of $^1/_8$-inch outside diameter tubing with 40-mil wall thickness.

Lightning Strokes to WGY

In 1938 a 20-mil chromium-plated copper cylinder was mounted on top of the then new WGY 635-foot radiator at Schenectady. The top of the cylinder was closed with a hemisphere of the same metal and thickness. When this was removed for examination in 1941, seven holes and several hundred small pits were found. The radiator was known to have been struck three times, the magnetic links showing −3,000, −7,800, and −30,000 amperes.

Of the seven holes, six were located in the 12-inch diameter hemisphere, mostly in the upper part, but none at the highest point of the sphere as installed. The cylindrical portion had a height of 14 inches, and one hole was found six inches from its lower edge. The pits were most numerous in the area above a line nine inches from the bottom of the cylinder. Twenty-nine of the pits had an appearance similar to that obtained from high-current laboratory discharges of one or two coulombs.

Concerning the Holes Burned

With reference to the appearance and size of holes some comment is desirable. While the WSM sphere showed some very small holes—as small as three square millimeters—such small holes could not be produced in the laboratory in copper sheets. The smallest hole obtained had an area of 28 square millimeters. However, in galvanized iron sheets, holes as small as 1.5 square millimeters could be produced.

This effect has been attributed to the close proximity ($^1/_4$ to $^1/_2$ inch) of electrode to the sheets under test. A tapered carbon electrode was used to avoid the effect of the metal of the electrode on the calibration. Although the electrode begins to glow at 60 coulombs, very little gas is given off. Brass electrodes were tried but consistent results were not obtained.

It is expected that the only difference to be obtained from a longer arc would be the possibility of forming smaller holes in copper sheets. Within the range investigated—spacing $^1/_4$ inch to $^1/_2$ inch—the character of the holes is not changed, indicating that the electrode effect is not appreciable. The close proximity of the electrode possibly has the effect of spreading the core of the arc wider than would be the case in a lightning stroke. However, the holes produced showed the same characteristics as those produced by natural lightning as evidenced on the WSM sphere.

The tests on metal sheets up to 100-

Figure 12. Lightning damage at W. H. Joslyn house, August 4, 1939. Pelham Road near Amherst, Mass.

Furrow in ground was dug by lightning as it left Joslyn house and headed toward neighboring Rouleau home

Figure 13. Destruction of pine tree by lightning discharge

Top of tree blown off by high current peak. Stump burned by continuing discharge

mil thickness indicate the following relations:

$$C = \frac{A}{25} \times t^{0.9} \quad (t = 0 \text{ to } 35 \text{ mils})$$

$$C = \frac{A}{245} \times t^{1.54} \quad (t = 35 \text{ to } 150 \text{ mils})$$

where

C = coulombs
A = area of hole in square millimeters
t = thickness of sheet in mils

Such equations are reasonably accurate for copper and galvanized iron and may be used to estimate the coulombs in a given lightning stroke. The use of the curves of Figure 5 for the individual metal is more accurate, but tests of this nature do not permit close calibration, the variation from the curves shown in Figure 5 being as much as 40 per cent for some individual points.

That the hole burning is a function of coulombs rather than i^2t has been verified by the fact that equal holes are burned when equal coulombs in the arc are produced with widely different current amplitudes. The test currents ranged from 50 amperes to 600 amperes, which is in the range of natural lightning continuing discharges. Tests at high currents with high coulomb values have not been made, but the calibration data given in Figure 5 should not be used for high currents. Bellaschi[2] similarly showed that burning of solid heavy electrodes is dependent upon coulombs.

In Figure 7 are shown holes burned in a five-mil, nickel-plated copper sheet with discharge currents of 40,000 amperes crest. The small holes and burns numbered 1–5 were produced with the sheet grounded. The larger holes 6–9 were obtained with the sheet midway between the line electrode and the ground electrode. The jagged character of the holes is apparent, especially in number 9 where the electrode distance was increased from $^5/_{16}$ to $2^3/_4$ inches. There is no evidence of the copper beads lining the hole as is observed on the sphere and the corresponding test sheets. As the current amplitude is increased, the explosive effect is increased as shown in Figure 8, which gives the effect of a 265,000 ampere 30-coulomb discharge to a grounded copper sheet of ten-mil thickness. The same impulse applied to a 25-mil copper sheet did not rupture it but did produce a large dent in its surface. On the other hand, a 25,000-ampere one- to two-coulomb discharge will form a bright bead on a 20-mil copper sheet but will not puncture the sheet. In the explosive type or high current discharge many factors have to be weighed besides current amplitude, while the charge in the long-duration low-current continuous discharge can be computed with fair accuracy.

The tests indicate a possible source of fire with thin metal-roofed buildings, if inflammable material is close to the metal or in such position that molten metal may drop on combustible materials. If thin metals are to be used for covering, then elevated air terminals should be used to keep the arc away from the building and a suitable path to ground provided to prevent damage at joints in the metal structure.

Tests on Steel Plate

In view of possible lightning strokes to metal containers of explosive gases of liquids, tests were made with the equipment shown in Figure 1 with the following result. A $^3/_8$-inch steel plate was tested with 430 coulombs in the arc. Results of such tests are shown in Figure 9. The plate could not be punctured but a crater-like hole was formed of $^3/_{16}$-inch depth and 180 square millimeters area. To puncture such a plate several thousand coulombs would be required.

Lightning Stroke to Home

Of the many lightning damage cases which the authors have investigated, that which occurred near Amherst, Mass., during the summer of 1939 is perhaps one of the most interesting. Lightning struck the home shown in Figure 10, resulting in the external damage shown. The upper portion of the chimney had been eliminated, and the chimney was cracked throughout its length. A hole having an area of 345 square millimeters was found in the 15-mil galvanized-iron shingle roof at a point about three feet from the chimney and in the direction of the damaged corner of the building shown in Figure 10. Several small holes were found in a shingle, which apparently had been located at the corner of the roof above the damaged corner. No evidence of fire could be found anywhere, although in the kitchen there was a considerable burn between a sink and a nearby pipe, which had a combined effective resistance to ground of 47 ohms. This was the only ground in this house. There was also considerable burning between the cover of an ice box and the zinc lining. Nearly all of the windows on the ground floor were blown outward, showing the high pressure developed within the house. Two persons were in the house, one upstairs to the right of the chimney, and the other in the kitchen to the left of the door shown in Figure 10. Neither was hurt.

There was no wiring of any sort in this home. In Figure 11 is shown another home, 155 feet away, which had a three-wire service with the usual appliances connected. In the cellar was a driven ground of 430 ohms. In addition, two grounds having a combined resistance of 215 ohms were driven at the service pole located 110 feet from the house of Figure 10, and 80 feet from the house of Figure 11. A portion of the path of the lightning discharge is shown in Figure 12. At the point illustrated the channel in the earth was about three feet in width and about 15 inches in depth. It continued with two-foot width and about the same depth for a distance of 74 feet where it split into two parts, one to continue 88 feet to the ground rod in the cellar of the house of Figure 11, and the other to travel 81 feet to the ground rods driven at the base of the service pole. The electric equipment in the wired house was in operating condition after the storm, although the cellar windows were blown out as the result of the pressure developed in the spark to the driven ground rod inside close to the cellar wall.

From magnetic effects observed, it was concluded that the current in the neutral wire was of the order of 30,000 amperes of a slow rate of rise and indicated a negative-polarity stroke to the unwired house of Figure 10. A calibration of the shingle burns indicates a coulomb value of 210 for the larger burn and 30 coulombs for the smaller burns.

In reconstructing what happened, it is probable that the stroke was negative, beginning with a current peak of the order of 200,000 amperes, followed by a continuing current having a coulomb value of 240. The physical damage seen in Figures 10 and 12 resulted from the high current peak. After the chimney exploded, apparently the path shifted to the burned points found on the roof. With the high coulomb value of the continuing current, one would have expected a fire to ensue, but no evidence of this could be found, indicating that the inflammability of the various paths was such as not to cause fire.

This case is given here, because some knowledge exists as to the magnitude of the lightning current which caused the damage observed. This again illustrates what may happen when good grounds are not available when lightning strikes.

The pine tree shown in Figure 13 is mute evidence of the same type of lightning discharge just described. This tree struck by lightning exploded a few feet

Abnormal Currents in Distribution Transformers Due to Lightning

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Synopsis: Abnormal currents in distribution transformers due to lightning are analyzed both theoretically and from field experiences. Under certain conditions of direct stroke transferred through the arrester to the neutral of the secondary winding, excessive currents may wreck the secondary windings by electromagnetic forces. Long-duration surges, or shorter repeated surges, saturate the transformer cores producing greatly increased surge currents in the primary windings which influence fuse failures. The saturation of the cores by unidirectional lightning surges also brings about increased power-frequency magnetizing currents influencing sectionalizing-fuse and circuit-breaker operations.

A GREAT deal of research has been done and many papers have been written dealing with the problems of overvoltages under lightning conditions. It has been assumed generally that, because of the relatively high inductance of transformer windings, very little lightning current builds up within them. There are, however, certain conditions under which the lightning current may enter the secondary windings of grounded-neutral distribution transformers and rise to such magnitudes as to develop electromagnetic forces sufficient to destroy that winding by mechanical stress. Also, for long-duration single or multiple lightning surges enough current builds up through the primary winding to saturate the core; and the consequent rate of increase of current in the winding becomes more rapid, and the current is finally limited only by the d-c resistance of the primary winding. These latter currents are generally insufficient to damage the winding, but they are important in the determination of fuse failures[1] and sectionalizing operation under lightning conditions.

Another source of abnormal transformer currents is that of large magnetizing inrush currents brought about by surge conditions, which will be primarily important in the operation of fuses or breakers. These various phenomena of abnormal transformer currents are discussed further in this paper, with special reference to distribution transformers on rural lines.

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Direct-Stroke Lightning Currents in the Secondary Windings

Under certain circumstances of direct lightning strokes to the primary line, very large currents may go through the secondary winding when the lightning arrester functions to protect the primary. Occasionally the effect of such currents is completely to disrupt the windings, as shown in Figure 1. There is no present protection scheme in use which protects against such conditions. The transformer was connected as shown in Figure 2. The lightning arrester effectively by-passed to the ground lead the resulting current from a direct stroke to the line, and the primary winding was perfectly protected, as determined by subsequent test. The voltage of the secondary wires rose, together with that of the transformer case, to the value of the surge-impedance drop of the grounding wire impedance and ground resistance, and another flashover to ground occurred, this time on the customer's premises. Current in the two wires on each side of the grounded neutral to the customer ground fault went through the secondary winding. Since the current went from the transformer case at raised potential into the neutral connection of the transformer coil, and from there into the winding halves in opposite directions, the magnetic fields of the two halves of the secondary winding canceled out to a high degree, because of the close coupling. The leakage-reactance drop and also the resistance drop were not sufficient to flash over the bushing or the normal shunt safety gaps in use. Thus the current continued to go into the secondary coil sections in opposing directions; the extreme resulting mechanical forces due to electromagnetic reaction distended the secondary winding, as shown at X in Figure 1, and actually cut several turns in two by jamming them against the core laminations.

Such conditions to a greater or lesser extent, must occur in almost every case of a direct stroke to line near a transformer installation. The paths for the lightning current through the transformer secondaries are indicated by arrows in Figure 2. The relative amount of current going into the windings varies with the relative ground resistances; in this case it was probably of the order of 20,000 amperes above the ground. Examination of the upper portion of the tree and the debris scattered over a considerable area showed no signs of burning; yet the stump was on fire when the owner of the land ran to the point where he saw the lightning strike. Evidently this stroke also began with a high current peak blowing the tree apart. The stroke persisted as a continuing current to the stump of the tree, which was still grounded, setting it afire. This was going on while the tree and the debris were in the air.

The data which have been collected thus far seem to indicate that the use of thin metal surfaces makes a fairly satisfactory means for collecting data with respect to the number of coulombs contained in natural lightning strokes, excluding the effects of the high current peaks which may be present.

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in each transformer section, but in most cases the current is apparently low enough to be harmless.

Insufficient field data are available on the frequency of such failures, and therefore it is uncertain whether protection against such faults is economically feasible. Also, it is beyond the scope of this paper to consider protective means beyond mentioning a few obvious measures such as:

1. Reduction of arrester ground resistance to a value considerably less than the customer's ground, although the customer's ground must also be kept low for his safety.

2. Application of very low breakdown-value protectors across the secondary bushings.

3. Placing of small reactors in the transformer secondary leads inside the tank, which will cause the bushing gaps to flash over and protect the secondary winding.

4. Placing the two secondary leads inside a waterproof metallic cable, the metallic covering of the cable serving as the neutral lead grounded to the case, and also serving as a supplement to the arrester ground when the cable is run underground to the customer.

Primary Winding Currents Under Long-Duration Surge Conditions

Very little surge current is built up in the primary winding until the transformer core reaches saturation, when the effective primary-winding inductance drops sharply; short-duration surges do not produce saturation. Long-duration or repeated surges equivalent to long surges can build up considerable currents, often sufficient to blow the usual primary protective fuse. The determining factors in this saturation phenomenon can be more readily analyzed by taking a specific field example of a 7,200-volt rural distribution system feeding a network of three-kva transformers, shown in Figure 3.

There are two possible conditions under which long surge waves may be present on the system. The arresters on the system may be functioning and, if they are of the conventional type, they will limit the peak voltage to about 55 kv, but this will drop at a slower rate than the incident wave; thus, in effect, producing a lengthened surge. On the other hand, especially in the case of repeated discharges, long surges may be present on the system without any arresters functioning on some of the later of the repeated discharges which may have dropped to below the breakdown point of the arrester. In the latter case the duration of the surge is influenced by the discharge path both from cloud to ground and within the cloud itself. Recent investigations[2,3] show such waves may be from 1,000 to 20,000 microseconds duration. A border-line case which would fit the above conditions of the arresters functioning or not functioning could be represented on the particular 7,200-volt line by a surge expressed as

$$e = E_s\epsilon^{-\alpha t} = 55{,}000\epsilon^{-0.693t}$$

This expression corresponds to a wave having a crest value of 55 kv and dropping exponentially to half value in about 2,500 microseconds. It will be noted that the second term of the more general expression for a surge, $e = kE(\epsilon^{-\alpha t} - \epsilon^{-\beta t})$, which is omitted, represents the rate of rise of the front of the wave. The duration of the "front" of the wave is so short in relation to the very long duration of the "tail" of the wave that it plays little importance in the determination of the final current through the winding; and therefore, the corresponding term is left off to simplify the mathematical presentation.

This surge wave is so long relative to the time of travel along the entire transmission line that the same potential can be considered applied at all the transformer installations, and the surge impedance of the line can be considered a negligible factor. This becomes clear when it is considered that the length of the wave of 2,500 microseconds corresponds to a time such a wave could travel 475 miles, or would travel back and forth in successive reflections on an average 50-mile rural system about ten times while dropping to half value. Hence the conditions can be considered essentially the same at each of the distribution transformers and may be schematically represented as shown in Figure 4.

The curves C and F, Figure 4, show the resulting current rise in the primary winding with the surge occurring at different points C' and F' on the normal 60-cycle wave, shown in Figure 5. The current begins to be appreciable only as the transformer core saturates. The hysteresis loop A-B-C-D-E-F-G in Figure 5 gives the normal variation of B-H as the transformer core changes its values of B to produce the equal but opposite sinusoidal electromotive force, $iR + N(d\Phi/dt)\cdot 10^{-8}$,

Figure 1. Showing the effect at X of electromagnetic stresses caused by lightning currents entering the secondary sections of a distribution-type transformer at the neutral-wire connection

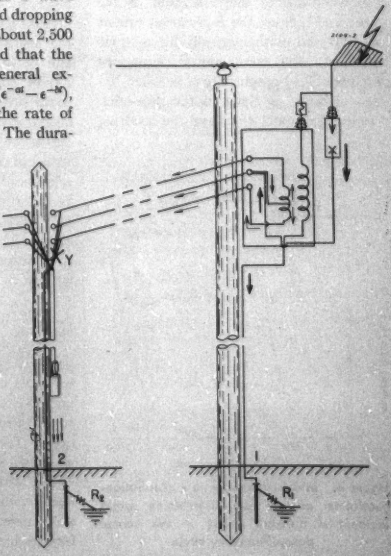


Figure 2. Schematic diagram of a typical rural-distribution-transformer connection with arrows indicating how the lightning current may penetrate the transformer secondaries

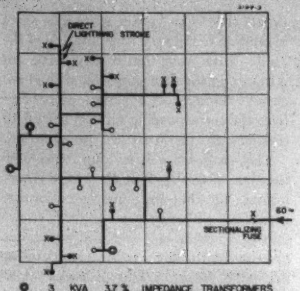
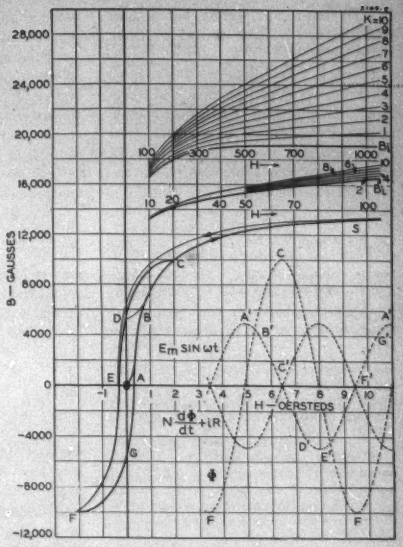

DIRECT LIGHTNING STROKE
SECTIONALIZING FUSE
60 ~
3 KVA 3.7 % IMPEDANCE TRANSFORMERS
1.5 KVA 3.7 % IMPEDANCE TRANSFORMERS
3 KVA 2.3 % IMPEDANCE TRANSFORMERS
FUSES AT ALL TRANSFORMERS ARE 2 AMP. RATING.
LOCATIONS OF BLOWN FUSES ARE MARKED "X".

Figure 3. Typical 7,200-volt rural single-phase section in which fuse failures were caused by lightning current penetrating the primary windings of the distribution transformers

Figure 5. Magnetization curve for the core of the typical distribution transformer

The dashed lines indicate relative flux-voltage relations under normal operation



which balances the applied electromotive force, $E_m \sin \omega t$. The B and electromotive force relationships are indicated in dashed lines on Figure 5, from which it is clear that a surge impressed at C' on the 60-cycle voltage wave conforms to C or maximum flux value, on the hysteresis loop, will cause a maximum flux increase along S; and, therefore, will result in the shortest time to core saturation. Similarly a surge at point F' on the 60-cycle wave would result in the longest time to saturation. The calculation of the growth of current must take into account these various states of magnetization of the core; and because the B-H curves cannot be expressed mathematically by a simple equation, the fundamental equations must be solved graphically or in a step-by-step manner, as given in the appendix. From these calculations and the resulting curves of Figure 4, it is clear that the time denoted by t_s elapsing before the core saturates and appreciable currents can develop varies with the point of surge incidence on the 60-cycle wave and lies in the range $t_s = 1{,}100 \pm 600$ microseconds.

The above range of t_s was determined for one specific 7,200-volt transformer of three-kilovolt-ampere rating. It follows, however, from the calculations (see appendix) that the time t_s is independent of the transformer kilovolt-ampere rating and of the voltage rating of the transformer, so long as the ratio of its voltage to the surge voltage remains the same. It also follows, from the calculations and the curves of Figure 5, that for the larger values of current as the core saturates, the relation of B to H increments or $\Delta B/\Delta H$ becomes a constant, and the problem may be solved as with constant parameters. The relation for the current due to a surge potential $e = E_s \epsilon^{-\alpha t}$, may be written as

$$i = \frac{E_s}{R - \alpha L}\left[\epsilon^{-\alpha t} - \epsilon^{R/L(t - t_s)}\right]$$

where L is the inductance of the circuit with the core saturated, t_s is $1{,}100 \pm 600$ microseconds, depending on the point of surge incidence on the power frequency cycle; the values of i up to $t = t_s$ being relatively small and considered zero.

The derived simplified equation lends itself readily to the examination of possible currents flowing into various transformers having different impedance characteristics. Thus, Figure 6 shows possible currents due to the surge alone flowing into two transformers of different impedances but of the same kilovolt-ampere and kilovolt ratings. These currents are of sufficient magnitude to cause the protective fuses in the transformer-primary-circuit leads to fail, as was proven by instances of fuse failures on *unenergized* lines under lightning conditions. Conclusive evidence that the relative currents are as calculated is given by the field case summarized in Figure 3, where every fuse failed at a 2.3 per cent impedance transformer but where none failed at any of the higher impedance transformers. The greater current associated with the lower impedance transformer, as shown

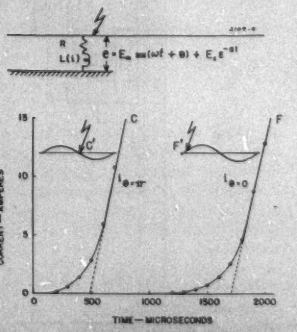


Figure 4. Initial current rise in a distribution-transformer primary due to lightning surges incident at different points on the normal power-frequency cycle

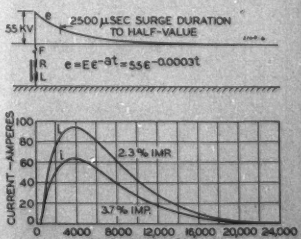


Figure 6. Incident surge wave and resulting current in the primary windings of three-kilovolt-ampere, 7,200-volt distribution transformers having per cent impedance values as marked on the curves

in Figure 6, accounts for the selective action noted. The solution of the fuse-failure problem is definitely not, however, the use of high-impedance transformers. In this particular case all of the fuses were of the same rating; and none failed on the high-impedance transformers, because these transformers were overfused relative to their impedance and, therefore, were actually unprotected against normal overloads.

Conclusion

Direct lightning strokes may cause very large currents to penetrate the secondary windings of distribution transformers with destructive effects, even though the primaries are perfectly protected. It is important, therefore, to determine the actual extent and frequency of occurrence of this type of failure in practice.

Long-duration surges cause relatively large currents to build up also in the primary windings of distribution transformers, as analyzed in this paper. Field experience with fuse failures and laboratory research by the writers with simulated surge conditions, have checked the validity of the analytical approach. Oscillographic records obtained in this research agree closely with Figure 6. Conclusions on the effect of variations of incidence of a surge on the 60-cycle wave follow readily and accurately from the detailed analysis in the appendix and elsewhere in this paper. Published experiments by Bergvall and Beck[4] with direct currents equivalent to long-duration surges applied to transformers are also in reasonable agreement.

The calculations of Table I in the appendix, extended over a number of cycles, show that even after the surge voltage has completely disappeared a high magnetizing current transient results, due to the high degree of saturation in the core. Reference to equation 5 in the appendix shows that the flux increment, due to a small surge incident on the transformer 60-cycle wave at a point corresponding to low core flux value, may be written

$$\sum \Delta B = \sum \frac{\omega B_m}{E_m} E_s \epsilon^{-at} \Delta t$$

since iR would then be negligible during the surge-incidence time. The total flux increment due to a surge $E_s\epsilon^{-at}$ would be

$$\int_0^s \frac{\omega B_m}{E_m} E_s \epsilon^{-at} dt = \frac{\omega B_m E_s}{a E_m}$$

It follows, therefore, that every surge, no matter how small, would cause a certain shift in flux and would produce a magnetizing transient. These transients, although usually more severe, are of the same character as the magnetizing inrush currents experienced when energizing a transformer at certain points on a 60-cycle wave. This fact is of importance in examining possible faulty operation of fuses and breakers. An interesting proof that such "induced" magnetizing inrush currents may cause faulty fuse and breaker operation is given by cases of recent outages during periods of severe sun-spot activity which resulted in long-duration relatively constant voltages across the transformers, which although quite different in magnitude were comparable in effect to long-duration repeated lightning surges.

Although complete protection methods have been developed, further researches and field studies are necessary to determine the frequency of occurrence of these problems in actual practice.

Table I. Step-by-Step Solution of Current Due to a Lightning Surge, $55{,}000\epsilon^{-0.0003t}$ Superposed at the 180-Degree Point of the Normal Power-Frequency Cycle

$$\Delta B = -10\,000\ \Delta\cos(0.000377\,t + \pi) - 67\,700\ \Delta\epsilon^{-0.0003\,t} - 0.1\,i\,\Delta t$$

①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
t	Δt	ωt	$\cos\omega t$	$10^4\Delta\cos\omega t$	at	ϵ^{-at}	$\Delta\epsilon^{-at}$	$-67700\Delta\epsilon^{-at}$	$\bar{\imath}$	$-0.1\,\bar{\imath}\,\Delta t$	ΔB	$\Sigma\Delta B$	$i=\Sigma 0.1\,i$ H
t	Δt	0.000377×①	cos ②		0.0003×①	$\epsilon^{-④}$		$-67700\times⑧$			③+⑨+⑪		
0		0	1.0000		0	1.0000						10 000	0.02
100	100	0.0377	0.9993	−7	0.03	0.9704	−0.0296	2010	0.03	−0.3	2000	12 000	0.045
200	100	0.0754	0.9971	−22	0.06	0.9418	−0.0286	1940	0.10	−1.0	1920	13 920	0.16
300	100	0.1131	0.9936	−35	0.09	0.9139	−0.0279	1890	0.3	−3	1850	15 770	0.52
400	100	0.1508	0.9886	−50	0.12	0.8869	−0.0270	1830	0.93	−9	1770	17 540	1.35
500	100	0.1885	0.9825	−63	0.15	0.8607	−0.0262	1770	2.0	−20	1690	19 230*	2.70
600	100	0.2262	0.9745	−78	0.18	0.8353	−0.0254	1720	4.3	−43	1600	20 830	5.90
700	100	0.2639	0.9654	−91	0.21	0.8106	−0.0247	1670	8.3	−83	1500	22 330	10.80**
800	100	0.3016	0.9549	−105	0.24	0.7867	−0.0239	1620	13.1	−131	1380	23 710	15.40
900	100	0.3393	0.9430	−119	0.27	0.7634	−0.0233	1580	17.5	−175	1290	25 000	19.70
1000	100	0.3770	0.9297	−133	0.30	0.7408	−0.0226	1530	21.7	−350	1180	26 180	23.63
2000	1000	0.7540	0.7280	−2017	0.60	0.5488	−0.1920	13000	35.9	−3590	7390	33 570	48.26
3000	1000	1.131	0.4257	−3023	0.90	0.4066	−0.1422	9620	50.8	−5080	1520	35 090	53.33
4000	1000	1.508	0.0628	−3629	1.20	0.3012	−0.1054	7140	50.7	−5070	−1560	33 530	48.13
5000	1000	1.885	−0.3090	−3718	1.50	0.2231	−0.0781	5280	43.5	−4350	−2790	30 740	38.83

* Complete saturation of iron in core, beyond which $\Delta B = K\Delta H$.

** Values beyond B-H curve obtained from $\Delta i = 0.01\,\Delta H = 0.01\Delta B/K$.

Appendix. Solution for Current in Transformer Due to Lightning Surge Superposed on the Normal Power Cycle

The fundamental relationship for the transformer with a total voltage e across it, composed of the normal operating voltage $E_m \sin \omega t$ and a superposed surge voltage $E_s\epsilon^{-at}$ may be written as

$$\begin{aligned} e &= E_m \sin(\omega t+\theta) + E_s\epsilon^{-at} \\ &= N(d\phi/dt)\times 10^{-8} + iR \\ &= A(dB/dt) + iR \end{aligned} \tag{1}$$

where ϕ represents the total value of the flux linking the primary winding, including the air space around the core, that is, the leakage inductance $L(di/dt)$ drop. This leakage inductance is introduced in the calculation by choosing the graph corresponding to the proper value of K in Figure 5, the value of K being equal to the ratio of total leakage flux (excluding the contribution of the core) to the leakage flux which would be obtained in the space occupied by the core. External inductance of transmission lines, and so forth, can also be included in determining the value of K, as suggested by Steinmetz[5] in solving the somewhat similar problem of determining magnetizing inrush current. The value of the constant A can be determined from the physical characteristics of the winding or from the known maximum flux density under normal operating voltage conditions. Neglecting the iR term for normal magnetizing currents, and for normal steady-state conditions

$$E_m \sin \omega t = A(dB/dt)$$

from which

$$dB = (E_m/A)\sin \omega t\,dt \tag{2}$$

$$B = (E_m/A)\int \sin \omega t\,dt = (-E_m/A)\cos \omega t$$
$$B_m = E_m/\omega A$$

and hence,

$$A = E_m/\omega B_m \tag{3}$$

Thus, substituting this value of A in equation 1 for surge conditions

$$\begin{aligned} e &= E_m \sin(\omega t+\theta) + E_s\epsilon^{-at} \\ &= (E_m/\omega B_m)(dB/dt) + iR \end{aligned} \tag{4}$$

For a solution of equation 4, dB/dt may be written in finite increment form $\Delta B/\Delta t$, giving

$$\Delta B = (\omega B_m/E_m)(e - iR)\,\Delta t \tag{5}$$

The values of the total potential e composed of $E_m \sin(\omega t+\theta)$ and $E_s\epsilon^{-at}$ in equation 5 must be the average values over the interval Δt. To avoid the approximation of finding the average, $E_m \sin(\omega t+\theta)dt$ may be written as $-d[(E_m/\omega)\cos(\omega t+\theta)]$, and $E_s\epsilon^{-at}dt$ as $-d\left[\frac{E_s\epsilon^{-at}}{a}\right]$ so that, in substitut-

ing increments for the differentials, equation 5 may be written as

$$\Delta B = -B_m \Delta \cos(\omega t + \theta) - \frac{\omega E_s B_m}{\alpha E_m} \Delta \epsilon^{-\alpha t} - \frac{\bar{i} R \omega B_m \Delta t}{E_m} \quad (6)$$

The values of i remain to be averaged over the interval Δt, so that, where variations of i are rapid, it may be necessary to use shorter intervals of t. The values of ΔB are added to the preceding values to give the total B, and the corresponding values of i are determined from the B-H curve of Figure 5 in the step-by-step manner indicated in Table I. The relation of i to H depends upon the number of turns in the winding, N, and the mean length of the magnetic path, l;

$$H = \frac{0.4\pi N i}{l} \text{ or } i = \frac{Hl}{0.4\pi N} \quad (7)$$

For a typical three-kilovolt-ampere, 7,200-volt distribution transformer it was found that for $E_s = 55$ kv, as shown for the surge $e = E_s \epsilon^{-\alpha t}$, and for the actual constants as determined from the transformer of $B_m = 10{,}000$ and $E_m = 7{,}200\sqrt{2}$ or 10,200 volts, and $R = 280$ ohms, equation 6 for ΔB could be expressed with convenient coefficients for step-by-step calculations, to within two to three per cent probable error, as

$$\Delta B = -10{,}000 \Delta \cos(0.000377 t + \theta) - 67{,}700 \Delta \epsilon^{-\theta \cdot 0008 t} - 0.1 \bar{i} \Delta t \quad (8)$$

with t and Δt expressed in microseconds, and where, for the particular transformer $l = 32$ inches and $N = 6{,}240$ turns, the values of i are given by

$$i \approx 0.01 H \quad (9)$$

with H corresponding to the various values of B determined for the proper value of K (in this case $K = 3$) from Figure 5.

The initial value of B in Table I is taken as that corresponding to the point on the normal 60-cycle voltage wave at which the surge is incident. The particular value taken in the given tabulation is that value nearest saturation, or with an initial value of $B = B_m = 10{,}000$, corresponding to the incidence of the surge at the zero point C' on the 60-cycle wave, or where $\theta = \pi$ in equation 6. It is clear from the tabulation and from the corresponding plotted curve in Figure 4, that the values of current are relatively small until the time when the core is very near the saturation point, or until $t_0 = 500$ microseconds in this case. Similar calculations for a point of incidence of the surge corresponding to $\theta = 0$ in equation 6 and to F' in Figure 5 gives, for the equivalent time to saturation t_0, the value of 1,700 microseconds. Thus the time elapsing before the core saturates and appreciable currents can develop varies with the point of surge incidence on the normal voltage wave, and for the given ratio of

$$(E_s/E_m) = \frac{55{,}000}{10{,}200}$$

lies in the range

$$t_0 = 1{,}100 \pm 600 \text{ microseconds} \quad (10)$$

The above value of t_0 was determined for one specific 7,200-volt transformer of three-kva rating. It is of interest to refer back to equation 6 from which it will be noted that while i is still small, that is, before $t = t_0$, the values of ΔB due to the surge voltage are proportional to (E_s/E_m). This proportionality means that for the same ratio of surge voltage to line voltage the values of $t_0 = 1{,}100 \pm 600$ microseconds will hold closely, irrespective of the transformer rating, and will vary only in response to (E_s/E_m). Thus, since there is a fairly well-established ratio of allowable surge voltage to 60-cycle voltage on distribution lines the values for t_0 are valid for all distribution transformers, irrespective of kilovolt and kilovolt-ampere ratings.

Another interesting development which follows upon examination of Table I and Figure 5 is that, as the core saturates the relation $(\Delta B/\Delta H)$ becomes a constant and the problem may be solved approximately with equivalent parameters. If one neglects the much smaller component of the 60-cycle voltage effective under the surge conditions of saturation, the current due to a surge potential $e = E_s \epsilon^{-\alpha t}$ may then be found from,

$$i = \frac{E_s}{R - \alpha L} [\epsilon^{-\alpha t} - \epsilon^{-(R/L)(t - t_0)}] \quad (11)$$

where L is the inductance of the circuit with the core saturated, t_0 is $1{,}100 \pm 600$ microseconds dependent on the point of surge incidence on the 60-cycle wave, and the values of i up to $t = t_0$, being small, may be neglected.

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Current Ratings of Electronic Devices for Intermittent Service

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Synopsis: Electronic devices are used extensively for switching, relaying, welding, and similar service resulting in intermittent loads. In the paper methods for assigning standard ratings suitable for such intermittent loads are investigated, both for single-anode tubes and tube circuit combinations. Vapor-filled tubes with oxide-coated filaments are treated somewhat in detail in order to develop the basic considerations. Other types of tubes, such as the pool-type and cold-cathode, are only briefly discussed. A method of rating which seems generally applicable is proposed, with the suggestion that its suitability for the great variety of conditions encountered be further investigated.

THE assignment of ratings especially suited for intermittent service is desirable, if it results in more economic use of devices than the present practice of assigning continuous ratings. The subject is of particular importance in connection with tubes, because they are used so extensively for intermittent operations such as switching, relaying, signaling, spot-welding, and so forth. It is intended in this paper to examine the possibilities of assigning intermittent service ratings to electronic devices, giving due consideration to the methods proposed in the recent AIEE report No. 1-A on "General Principles for Rating of Electrical Apparatus for Short-Time, Intermittent, or Varying Duty," by standards co-ordinating committee 4.[1]

In any analysis of the rating of electronic devices the following must be kept in mind:

1. The flow of current through each anode, and consequently through a single-anode tube, is intermittent in nearly all applications. This is shown in Figure 1, case A_1, which illustrates the current flowing with a single-anode rectifier. The same condition applies with a single-phase full-wave rectifier for each anode. Case C_1 shows the current in each single-anode tube for three-phase rectification; similarly E_1 applies to six-phase arrangements. In some applications the time of current-flow is even less, as in the ignitor circuit tubes of igunitrons, illustrated by case G_1. If the application is such that the current-flow periods repeat continuously, it is customary to consider it continuous service, which for each anode means continuously repeating pulsations of the current. Regardless of this continuous feature, it must be realized that dependent upon the duration of each pulsation and the amount of idle time between pulsations, different current rating values may have to be assigned for the different cases of Figure 1 and similar variations, in order to bring about economical use of the electronic devices.

2. In all electronic arrangements consisting of two or more single-anode tubes, careful distinction must be made between the rating of individual tubes and that of the complete tube combination. Cases B_1, D_1, and F_1 show the output of two-, three-, and six-tube arrangements corresponding to the single-anode currents of cases A_1, C_1, and E_1, respectively.

3. The output of the tube combination may be continuous as discussed so far, or intermittent as illustrated for equal time on and off in B_2, D_2, and F_2 of Figure 1. The currents in the individual single-anode tubes for these cases are shown in A_2, C_2, and E_2 respectively. The current here is intermittently pulsating. G_2 shows an intermittent load for short-time individual pulsation as might be found in the individual ignitor circuit tubes used in seam-welding. Ratings for such intermittent tube loads may be different from those of the previously described continuously pulsating loads.

Rating of Single-Anode Tubes

Depending upon the type of tube and type of load, the permissible rating of a single-anode tube may be limited by any one of the following factors:

(*a*). *Heating of the Tube as a Whole.* With the usual assumption of constant voltage-drop in gas-filled tubes, it is customary to consider the average current as the principal factor in this respect. Investigations by Knowles and McNall[2] indicate, however, that with short-time pulsations in a hot-cathode tube the assumption of constant voltage-drop does not hold true, and this may have to be considered under some conditions. (In the case of rectification of frequencies of hundreds or thousands of cycles, there is considerable additional anode heating due to positive ion bombardment of the anode during the inverse part of the cycle, a fact which, of course, must receive due consideration.)

(*b*). *Heating at the Lead-in Conductors and Seals.* This is influenced largely by the rms current, and if it is too high difficulties may develop. (Unfortunately the heating of the lead-in conductors and of the tube as a whole are interdependent, making a clear-cut distinction between the limits imposed by the average current and the effective current difficult.)

(*c*). *Values of the Individual Current Pulsations and Their Duration and Frequency.* These may be important factors in limiting tube ratings for a number of reasons dependent on the physical phenomena entering into the operation of various types of tubes. (The sparking tendency of oxide-coated filament tubes and the back-fire phenomena in pool-type tubes are examples of this.)

(*d*). *Requirements for Satisfactory Life of the Tubes.* Even though the limitations imposed by items a, b, and c have been taken into account to assure satisfactory operation, rating values may have to be made the subject of further adjustments to assure satisfactory life of the tube. (The life of oxide-coated filaments or the life of the covering of cold cathodes are examples of this. The electron emission in a hot-cathode tube decreases during life, and in many cases the end of life is determined by lack of cathode emission. Therefore, tests or ratings involving peak-current-carrying capacity, as well as any other current rating, of the tube must take this into account.)

Separate consideration will have to be given to each type of tube for various service conditions before any plan toward a reasonably uniform method of rating can be devised. As a contribution toward a satisfactory system of rating a number of typical cases will be considered in the following.

Vapor-filled tubes with oxide-coated filaments will be considered first. Rating data for those tubes usually give the continuous average current rating and a limiting peak or crest value for the current. The latter ranges in some tubes from four to six times the continuous average current value, or conversely, the continuous average is 25 to 16.6 per cent of the specified peak value. In Figure 1 the rms and average current values are indicated in per cent of the crest values for each of the cases shown. It will be noted that in all cases of the single-anode tube currents except A_1 and C_1 the average current is less than 16.6 per cent. This in turn means that with the data indicated above, which are those usually given, the average current is the limiting factor in cases A_1 and C_1, while in all other cases the specified peak current limits the permissible load, regardless of the duration and frequency of the current impulses. A question therefore arises as to whether better utilization of these devices might not be brought about by some other method of specifying ratings more suitable for loads with short-time pulsations. Knowles and McNall have made an investigation on the sparking point of

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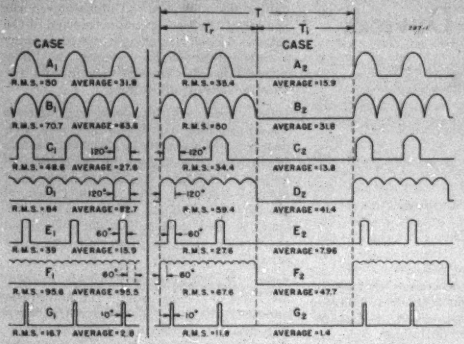


Figure 1. Typical load current for tubes and tube combinations

Cases A_1, A_2, C_1, C_2, E_1, E_2, G_1, G_2—Single anode currents

B_1, B_2, D_1, D_2, F_1, F_2—Currents for multi-anode arrangements

A_1 to F_1—Continuous loads

A_2 to F_2—Intermittent loads

Rms and average current values in per cent of crest values are indicated in each case

the filament as depending upon current and time. Some of their results are rearranged in Figure 2. It will be noted that with the minimum filament voltage of 2.25 volts, peak currents of 2.75 amperes for long durations of the pulsation are indicated. The curve also shows that the permissible peak loads can be increased by 2 per cent, 11 per cent, 32 per cent, and 80 per cent, for 180, 120, 60, and 10 degrees of the 60-cycle wave respectively; especially in the last two cases the gain is appreciable and seems to make it worth-while to standardize on several ratings suitable for service with various short-time pulsations.

The underlying physical phenomena make it necessary to specify for each of such ratings:

1. The wave shape of the impulse.
2. The crest value of the impulse.
3. The duration of the individual impulse.
4. The frequency at which the impulses can be safely repeated.

1. *Wave shape.* The tests by Knowles and McNall were made with a rectangular impulse wave. In actual practice a variety of waves is likely to be found, some of which

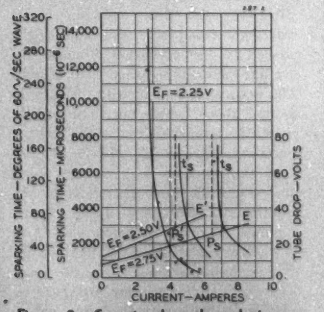


Figure 2. Current values dependent upon time above which cathode sparking may occur in a vapor-filled oxide-coated-filament tube

are shown in Figure 3. Although all of these waves have the same crest value and the same total time of current-flow, it is obvious that the effect of wave *A*, for instance, upon the sparking tendency and other characteristics of the tube is likely to be considerably different from that of wave *F*. Since it is obviously impracticable to establish a multitude of standards for all these wave shapes, a few typical ones will have to be selected as a basis for standardization; the choice will be determined largely by the wave shapes encountered in practical applications. A near rectangular or a sinusoidal wave, or both, may at times be selected for this purpose. In the application of tubes waves approaching a rectangular wave shape (see cases *C* to *G* of Figure 1) are at least as frequent as sine waves (*A* and *B*). The ease with which tests, especially life tests, can be made with a given type of wave should probably also have an important influence upon the final choice. Multiphase arrangements of single-anode tubes on 60-cycle circuits with at least six phases (six tubes) give a wave shape approximating a rectangular wave (Figure 1, case E_1), and thus seem to be very convenient for test purposes. Therefore, standardization with such a wave shape of the impulse as a basis seems advisable in addition to standardization with a sinusoidal wave shape. Tests for standards with shorter impulses can be made either by increasing the number of phases (tubes) or by using basic frequencies above 60 cycles, depending upon the case. (In case of rectangular waves the steepness of the wave front may have to be specified, as destructive cathode bombardment may result if full anode current is drawn in time less than ionizing time of tube.)

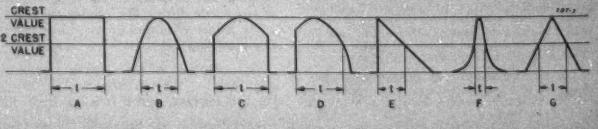
2. *The crest value of the impulse* has the advantage of simplicity over the use of rms or average values, since it obviates in many instances the necessity for calculating these latter values

3. *The time of the individual impulse* may be expressed in units of time such as milliseconds or microseconds; this practice has the advantage of being most generally applicable to all conditions found in actual practice. However, in some applications it may be convenient to express the time in degrees of some standard frequency, such as 60 cycles. (If a near-rectangular wave with a peak value and time specified is used as a basis for standardization, a question naturally arises as to how a tube so rated can be applied to pulsations having different wave shapes, such as shown in Figure 3. A practical and safe method can be based on the assumption that current values below a certain percentage (possibly below 50 per cent) of the peak value will have but negligible effect upon either the sparking tendency or the life of the tube. If this is true, the time *t* during which the current exceeds such percentage can be safely considered the effective time of the impulse, as illustrated in Figure 3. For example, an application with a wave shape as in case *F* would use a tube standardized on a much shorter rectangular impulse duration than would be used in *D*, although the total time of the current flow is the same in both cases.)

4. *The frequency at which the impulses can be safely repeated*, either continuously or for a limited period, must be given with the rating data. The tests on sparking tendency by Knowles and McNall were carried on with single impulses. If several such impulses were to follow each other at very close intervals, their effect might approach that of one longer interval, and sparking might result. If on the other hand the impulses are repeated at not too frequent intervals, the only result is likely to be a slight increase of the temperature of the filament, which in general will have a favorable effect on the operation at the lower filament voltages and no particularly harmful effect at the higher filament voltages. If the impulses are repeated too frequently for extended periods, limitations may also be reached, because of exceeding the safe average or rms currents of the tube, or because the life of the tube is decreased below satisfactory values. Various other limitations may have to be considered in this connection. The maximum frequency of impulses at which any of the limitations are reached can be readily determined by test, so that usually it is not difficult to establish a maximum frequency that is safe. In many arrangements connected to commercial circuits with a definite frequency, such as 60 cycles, a pulsating frequency in each single-anode tube in excess of the circuit frequency cannot be readily obtained and therefore is not of any practical value.

Since this paper deals essentially with current ratings, little mention has been made of the voltage conditions in the tube. It is of course appreciated that the various factors relating to current ratings

Figure 3. Typical wave shapes of current impulses which may flow in electronic devices



may be appreciably influenced by the operating voltage, the inverse voltage, the rate of rise of the inverse voltage, and so forth. This simply means that the complete rating structure must take such influences into account where they are of importance.

If pulsations as defined by the quantities previously discussed can be repeated continuously and without overheating the tube or any of its parts, no further information on the current rating is required. Practical applications of this kind are illustrated in E_1 and G_1 of Figure 1, as in these cases the average or rms values indicated are not likely to give unsafe temperatures. On the other hand, for applications A_1 and C_1 the average currents are likely to be in excess of safe values with continuously pulsating service. However, the current values of cases A_1 and C_1 can be safely applied for intermittent pulsating service, such as illustrated by cases A_2 and C_2. In rating tubes for such service, some additional rating information must be given. The most convenient method of rating to be applied here seems to be the duty-cycle method described in AIEE report No. 1-A. However, in applying this method to the case at hand, it requires some modification. The method calls for the specification of the maximum load time per duty cycle and a time factor k indicating the maximum ratio of load time or "on" time to the total time per load cycle. Due to pulsating nature of the load current, adherence to the exact wording of report 1-A would be confusing. In Figure 1 the time T_r indicates the time of the cycles during which pulsations occur, and T indicates the time of the total number of system cycles for one duty cycle. It is obvious that confusion can be avoided by giving the maximum permissible number of pulsations per load cycle and the ratio k of these pulsations to the total number of cycles of the system frequency per load cycle. These two values must be so chosen that satisfactory operation and life of the tube is assured. (Consideration has been given to the use of the service-factor method described in report 1-A, but it was found that the use of this method would unnecessarily complicate matters for the specific case without giving any compensating advantage. This really is to be expected, because the tube ratings under discussion depend upon many factors other than the rms current, which is one of the basic values of the service-factor method.)

In some respects the considerations up to this point have been specific to vapor-filled tubes with oxide-coated filaments. However, many of the conditions are the same as for most other types of tubes, at least qualitatively. Quantitatively, there may be marked differences, because the limitations are imposed by different physical phenomena. In an ignitron, for example, tendencies toward back-fire or the possibility of losing control of the tube by the ignitor will govern the amplitude and time of the current impulses and the permissible number of impulses per load cycle; the ratio of the permissible peak currents to the average and rms values is, however, many times larger than that with oxide-coated filament tubes; again various voltage conditions may influence some of the current ratings to a considerable degree. (While some of the restricting factors for the ignitron have been mentioned merely to point out certain differences, it should not be inferred that the ignitron involves more factors for satisfactory operation than a hot-cathode tube. A complete analysis is likely to indicate that on the whole the hot-cathode tube has more restrictions and complicating factors.)

Conditions with the cold-cathode tube are somewhat peculiar, as pointed out by G. H. Rockwood.[3] He gives a curve showing that with every load current of these tubes there is a certain total life in hours of current flow. He also indicates how the life of these tubes can be calculated from his curve for other than rectangular wave shapes. With this information it is possible to calculate for any required type and amplitude of load current the percentage of idle time which must be allowed for to assure a desired total life of the tube. In this manner the time factor k can be determined. There is no need in this case to specify the maximum number of impulses per load cycle, because the "on" time can be distributed in any desirable manner over the entire life of the tube. It will thus be seen that even the cold-cathode tube, although very different from the mercury-pool or the hot-cathode tube may be fitted into the general pattern of rating structure previously described.

The method of rating single-anode tubes suggested here should enable the designer of tube circuits to apply the tubes to best advantage. It unfortunately means the assignment of a number of different ratings corresponding to a variety of practical applications encountered. However, there seems to be no way of avoiding this with the many different phenomena and considerations entering into the operation of tubes. Any attempt to pattern tube ratings after the familiar type of ratings of most electromagnetic apparatus is contrary to the basic principles involved and therefore bound to result in misapplications or uneconomical use of the devices. If single-anode tubes are used by themselves, as may be the case with half-wave rectification, it may be advisable to give in addition to the rating structure described, the rms current and possibly the average current for the various ratings to assist in the selection of conductors, protecting devices, and so forth, connected in the tube circuit.

Rating of Tube Combinations and Circuits

For many practical applications, several single-anode tubes are used in combination, and in addition other apparatus such as transformers, reactors, capacitors, resistors, and so forth, are often employed in the combination, which has either a certain output as in the case of rectifiers or inverters, or a certain carrying-capacity as in applications involving control functions. The heating of most of the additional apparatus is determined by rms current values and usually the output or carrying-capacity of the entire combination in rms values is of principal interest to the user. (There are some exceptions to this, for instance, battery chargers, where the average current value is of importance.) For these reasons, and also because most users are accustomed to rms ratings, it is usually desirable to base the ratings of the combination arrangements wherever possible on rms values unless the load is of a type requiring pulsations, such as the ignitor circuit of an ignitron. (See G_2 of Figure 1.) For cases B_1, D_1, and F_1 of Figure 1, a continuous rms rating can readily be given, and for cases B_2, D_2, and F_2 the assignment of an intermittent or load-cycle rms current rating seems to be desirable. In most applications similar to D_1 and F_1 the difference between the rms and average ratings is of little practical importance, and in cases like B_1 filters are often used and minimize the difference. In B_2, D_2, and F_2 it is necessary on account of the tube characteristics previously discussed to specify the maximum duration of the "on" period per load cycle. It thus seems simplest to complete the rating structure by merely adding the time factor k, which is also limited by the tube characteristics as previously outlined.

Whenever additional apparatus is used in the circuit combination, certain rating limitations may be imposed by this apparatus. This may at times result in the

assignment of a time factor k smaller than that called for by the tubes. For the purpose of selecting certain standard devices such as fuses, switches, and so forth, connected in series with the tube device, the rms currents corresponding to the various load-cycle ratings should be known. Although with the factor k specified, the service factor can be readily calculated, it may nevertheless be desirable to give in the rating structure the service factor in addition to the time factor k. However, the service factor here cannot, as in most other apparatus, be construed as meaning that the "on" current and the "on" time can be varied at will as long as the service factor rms value is not exceeded. (Careful study of individual types of tubes and tube combinations may disclose some cases where this interpretation can be used. For the sake of flexibility in application, it is of course desirable to at least explore in many cases the possibilities of service-factor ratings which permit variation of current and time values at least below the rated current, and preferably also above this value, within the limit of an rms rating indicated by the service factor.)

Unfortunately the load-cycle method proposed is not very flexible in its application. It restricts the application of each load-cycle rating to but a limited variety of load-cycle conditions. The time $T = T_r/k$ (in which T_r is the specified maximum "on" time per load cycle) corresponds in some ways to the so-called "averaging" time used to some extent in tube specifications. Satisfactory results will be obtained with the rated current, if there are several load cycles instead of one during the time T, as long as the ratio of the total "on" time T_r to T does not exceed the value k. Additional load-cycle ratings have to be given for applications with different current values.

It may be advisable to illustrate briefly here the rating and application method for cold-cathode tubes. Assuming, for instance, a current of 50 milliamperes in the tube described by Rockwood, the life is found to be about 42 hours a tube. Therefore, if six such tubes are used in a six-phase arrangement, giving approximately rectangular wave shapes for the impulses of each tube, the combination would have a life of about 250 hours at 50 milliamperes. This, then, simply means that if a tube combination of this type is applied in service where a life of 10,000 hours is required, the factor k should not exceed the value of 0.025, which may be entirely practical for the relay service mentioned by Mr. Rockwood. For this case the maximum "on" time per load cycle could be given as 250 hours, although this would be of no practical significance in the usual relay application having a large number of short operating periods. The principal condition is that during the 10,000-hour life the total load time does not exceed 250 hours. (This is merely given as an illustration. With the relay service under consideration by Rockwood, an arrangement of one or two tubes is more likely to be used, and in such cases the impulses will be sinusoidal.)

The examples in Figure 1 all deal with rectification. Another function of tubes is that of switching or controlling alternating current for such purposes as spot welding, for instance. The individual single-anode tube here again carries pulsations which are either sinusoidal half waves as in Figure 3B, or sinusoidal waves with delayed starts as in Figure 3D. The current handled by the usual 2-tube combination is alternating instead of direct current as in cases B_2, D_3, and F_2 of Figure 1, and the load is as a rule intermittent. The operation of the individual anodes is the same as previously discussed; the conditions with regard to multianode arrangements are different only in so far as the current ratings for the combination should be expressed in rms values of alternating current, with all other factors handled as previously indicated.

Summarizing, the rating structure suggested here comprises:

For Single-Anode Tubes or Each Anode of a Multianode Tube	For Combination Arrangements
A. Continuous Ratings	
1. Wave form of impulses	1. Rms nominal current rating
2. Crest value of impulses	
3. Time of impulses	
4. Frequency of impulses	
B. Load-Cycle Ratings for Intermittent Service	
Same as above supplemented by—	
5. Maximum number of impulses per load cycle (or equivalent time)	2. Maximum active time per load cycle
6. Time factor k	3. Time factor k
	4. Service factors in addition to k

In devising a system of ratings, it must be considered that under many conditions the maximum "on" time T_r per load cycle and the time factor k are interdependent. Usually k has to be decreased with an increasing value of T_r. This is always the case when heating considerations are the determining factor. (See references 4 and 5 which demonstrate this in connection with machines and other apparatus. For tubes this is more fully discussed in a companion paper by Marshall and Arnott.[6]) For this reason T_r should not be chosen any larger than necessary for practical applications. By keeping T_r low, the value of k is favorably affected.

The above rating structure for continuous loads of single-anode tubes is not proposed to the exclusion of the present method of giving the average current for continuous ratings of tubes. It is intended essentially for cases where it results in more economical application of tubes than the conventional method, or where it is found more convenient. The use of the rating structure on the left side of the table is not necessarily limited to single anodes. It may also be found convenient for multianode arrangements primarily intended for supplying pulsations. If it should happen with cases G_1 and G_2 of Figure 1, for instance, that a single tube does not permit a frequency of pulsations high enough for a given application, a two-tube arrangement can be used to good advantage and may then be rated as indicated on the left side of the table. The rating structure on the right side is intended for all cases where direct or alternating currents are desired, and where pulsations or harmonics may or may not be present as an undesirable by-product of the circuits employed.

For load-cycle ratings the nominal rating is the value of the current during the load or "on" period of the load cycle. The service factor S is the ratio of the rms current for the entire time of the load cycle to the nominal rms current value during the "on" period.

Whenever tubes have a limited life, the expected life in hours must necessarily enter into the rating structure somehow, because the choice of the quantities given in the table may be materially affected by the assumed life. A typical example of this is the cold-cathode tube previously described.

As a rule, all of the quantities of the table except the service factor S, which may be given for convenience, are essential to definitely limit the application of the device to service it can handle satisfactorily. (There are a few exceptions to this, such as the cold-cathode tube where the indication of the maximum active time per load cycle is of no practical im-

portance.) However, the importance of the different quantities may vary appreciably with different tubes and applications, as may the reasons why the factors must be limited to the values given. In hot cathode tubes, for instance, the crest value of the impulses is quite a decisive value, while in many other types of tubes the maximum crest value is not such an important limitation. The maximum active time per load cycle may be primarily limited by heating considerations of various structural parts in hot-cathode tubes, while back-fire considerations or loss of proper control (also largely influenced by heating) may be most essential in some pool-type tubes. The time factor k, which determines the minimum idle periods, may be chiefly determined by heating consideration in a hot-cathode tube, while in a cold-cathode tube its value is determined essentially by the expected life of the tube. However, regardless of what these numerous variations may be, it seems that the suggested rating structure satisfies almost every conceivable condition that could be encountered in practice with continuous or intermittent service, although some exceptions to this can undoubtedly be found. It is fully realized that many factors (especially various voltage conditions) not discussed here in detail will have to be given careful consideration in the setting of current ratings. It is obvious that in the brief review of rating structures given here it would be impractical to attempt a comprehensive treatment of all phenomena involved. Some of the more important considerations not covered here will undoubtedly be pointed out in the discussion.

With the load-cycle current ratings so far discussed it has been assumed that they are intended for typical intermittent loads with definite requirements, as, for instance, the operation of relays designed for such current. Many applications like this are found in practice and can be taken care of by a single load-cycle rating. However, with many other tube arrangements, it may be desirable to give sufficient rating information to facilitate their application for a variety of intermittent service conditions. In Figure 4 the curve shown is intended to indicate the maximum "on" time permissible for a specific tube arrangement for various nominal load currents. Since it seems undesirable to list a great number of different current ratings, only a few, such as Pn_1, Pn_2, Pn_3, and Pn_4, are indicated in the figure. For each of these the maximum "on" time per load cycle can be given, as indicated by the values T_1, T_2, T_3, and T_4. In addition the value k would have to be given for each case. This then would make possible the application of the arrangement within its range of satisfactory performance for different applications, as intermediate values could be readily interpolated. A question arises, however, as to how a single nominal commercial rating should be selected for such a condition, especially for service where any of the loads are at times applied for considerable periods, as may occur with spot-welding arrangements for instance. There is not much choice between the different ratings in selecting one as a nominal commercial rating under these circumstances. The continuous rating P is so far from representing actual service conditions that it would not be a very satisfactory nominal rating. The maximum rating P_m is not very well defined because the time T_5 in Figure 4 may range from one cycle in the case of spot welding to the conventional period of one minute used in connection with the larger rectifier equipment.

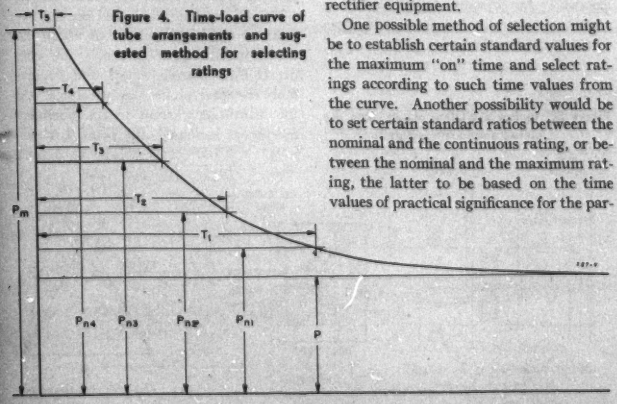


Figure 4. Time-load curve of tube arrangements and suggested method for selecting ratings

One possible method of selection might be to establish certain standard values for the maximum "on" time and select ratings according to such time values from the curve. Another possibility would be to set certain standard ratios between the nominal and the continuous rating, or between the nominal and the maximum rating, the latter to be based on the time values of practical significance for the particular type of tube or service, such as one cycle for spot-welding arrangements and one minute for large rectifying equipment. Some measure of uniformity could be accomplished by always using preferred numbers for these ratios, as indicated in Figure 4, where all the steps between the different ratings have been selected to be 25 per cent, corresponding to the coefficient of the ten series of preferred numbers. In this case the load Pn_3, which is about halfway between the continuous and short-time maximum rating, has been indicated by a heavy line to serve as the nominal commercial rating. It would seem highly desirable to devise some standard method for settling some of these questions, as it would greatly assist in the gradual evolution of a reasonably uniform method for electronic devices.

As previously stated, the suggestions given here are merely preliminary; final recommendations should not be given until considerably more work has been done in analyzing the various conditions. However, it is hoped that the brief outline will stimulate others to investigate various practical arrangements and applications for the purpose of determining whether the suggestions made here can be used, or whether they can be altered in some way to make them even more generally applicable. It is obvious that no system of rating applicable to all conditions can be devised; however, it seems entirely possible to develop a system capable of broad application and requiring only slight modifications for specific cases. At any rate, it should be possible to at least establish a nomenclature defining such terms as time factor, service factor, and so forth, which will be generally applicable and definite in its interpretation in all applications.

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Ignitor Excitation Circuits and Misfire Indication Circuits

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Synopsis: Several circuits are available for excitation of ignitron rectifiers. Static magnetic-impulse circuits are used for most applications. Several such circuits are discussed in some detail. Ignitor requirements are given, and circuit requirements affecting the choice of excitation circuits are indicated.

While ignitor failures are rare, they should be detected promptly to utilize all apparatus to the best advantage. Two conditions may arise

1. When two anodes operate in parallel from a single transformer winding.

2. When a single anode is connected to each transformer winding.

Means for detecting ignitor misfiring are described for both conditions.

AN ignitron is an electric valve in which the cathode spot or electric arc is established every cycle at the beginning of the conduction period of the main anode and is allowed to extinguish at the end of the conduction period. The arc is established by means of an ignitor, which is an element made of a high-resistance material and partly submerged in the cathode mercury pool. The ignitor is excited or fired by passing an electric current of sufficient strength through it into the cathode to establish a cathode spot or arc. Static magnetic-impulse excitation circuits have certain definite advantages over other ignitor excitation circuits.[1,2] The circuits here described satisfy certain operating conditions.

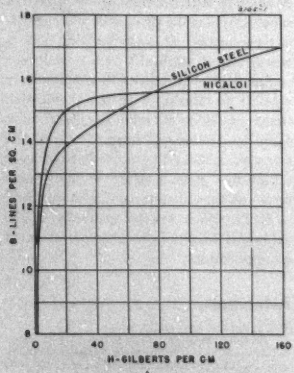


Figure 1. D-c magnetization curves

As current is built up in the ignitor to the firing value, power is consumed by the ignitor. At the instant the cathode spot appears most of the ignitor current transfers to the electric arc instead of passing through the whole length of the ignitor to the cathode, and the voltage across the ignitor suddenly collapses to arc-drop value. It is therefore desirable to build up the ignitor current rapidly to the firing point to limit the losses and the heating of the ignitor. Further, since the ignition current varies considerably from cycle to cycle, a rapid build-up of ignitor current will result in a more uniform firing angle.

Magnetic-Impulse Excitation Circuits

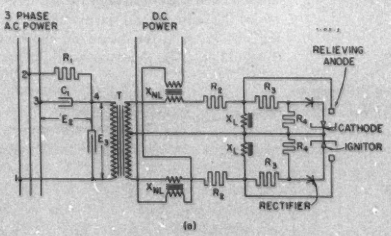
To obtain a rapid build-up of current or peaked current wave, a nonlinear reactor is used

In the high impedance region of such a reactor, that is, below its saturation point, there is substantially no ignitor current. As the impedance decreases, the rate of change of ignitor current increases. An abrupt transition to a peaked current wave requires a sharp knee in the magnetization curve of the reactor; a rapid rise of current requires a low saturated reactance. The use of an alloy such as Nicaloi (see Figure 1) and a well-interleaved core construction result in

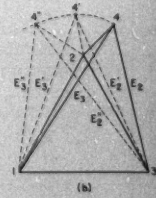
1. Sudden initiation of impulse current.

2. A maximum ratio of unsaturated to saturated reactance values. A capacitor may be used as a storage reservoir so that other circuit reactance will not reduce the rate of rise of the firing impulse current.

Figure 2. Ignitor excitation circuit using d-c biased nonlinear reactors



(a) Circuit diagram



(b) Vector diagram

In Figure 2 is shown a magnetic-impulse ignitor excitation circuit. Here a nonlinear reactor X_{NL} is used for each ignitor. This is necessary, because the reactor is biased with d-c ampere-turns to obtain a high peak current in the a-c winding in one direction but not in the other. The high peak current is allowed to pass through the ignitor in the positive direction, that is, from ignitor to cathode, while the low negative current is blocked by a dry-plate rectifier in series with the ignitor and instead flows through the linear reactor X_L. This circuit gives a peaked current wave having a base 60 electrical degrees long, that is, the arc is maintained for 60 electrical degrees of the fundamental frequency. In order to relieve the ignitor and the rectifier in series with the ignitor of this current after the arc has been established, a relieving anode and transfer resistor R_3 are used. The resistance R_4 reduces the inverse voltage impressed on the rectifier. The resistance R_3 limits the current in the circuit. Voltage control of the d-c output of an ignitron rectifier can be obtained by retarding the firing of the ignitors. The capacitors and resistance connected between the power supply and the primary of the transformer T, together with the amount of d-c saturation of the nonlinear reactors X_{NL}, permit voltage control by shifting of the ignitor firing.

The vector diagram shows how this shifting of phase is accomplished. Vector 1-4 is the voltage impressed on the primary of the transformer, and vector 4-3 the voltage impressed across the condenser C_1, and triangle 1, 2, and 3 represents the three-phase supply voltage. As the saturating current in the nonlinear reactors is increased, the point 4 travels

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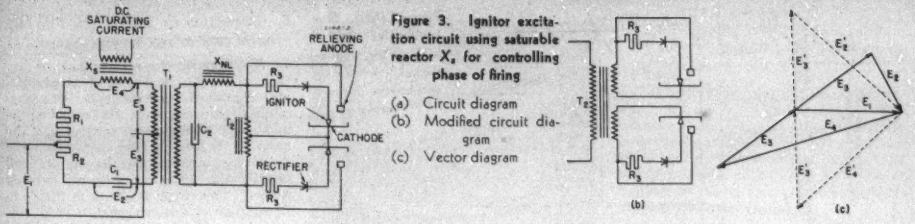


Figure 3. Ignitor excitation circuit using saturable reactor X_s for controlling phase of firing

(a) Circuit diagram
(b) Modified circuit diagram
(c) Vector diagram

on the locus, 4, 4′, and 4″. Thus the voltage impressed on the transformer advances as the saturating current is increased, and therefore the angle of ignitor firing advances with increasing saturating current. The purpose of resistance R_1 is to hold the amplitude of the voltage E_4 more nearly constant. The advantage of this firing circuit is the long period over which the arc is maintained.

Figure 3 shows an excitation circuit in which one nonlinear reactor X_{NL} is used to fire two ignitors. The nonlinear reactor is allowed to saturate in both directions, thus giving peak currents in both directions. An autotransformer T_3 is used to provide a return path for the ignitor current from the cathodes of the ignitrons. In case the cathodes must be insulated from each other, this can be done by making the autotransformer an insulating transformer as shown in Figure 3b. The shifting of the angle of ignitor firing in this case is accomplished by a saturable reactor X_s, together with a capacitor C_1. The resistances R_1 and R_2 keep the voltage wave across the transformer T_1 symmetrical and in this way insure that the two ignitors will fire 180 electrical degrees apart. Capacitor C_3 helps to increase the peak volt-amperes delivered to the ignitors.

In the vector diagram, E_4 is the voltage impressed on the transformer T_1 with low saturating current in the saturable reactor, E_2 is the voltage across the capacitor C_1, E_3 is the voltage across the a-c winding on the saturable reactor, and E_1 is the line or supply voltage. As saturating current in the saturable reactor is increased, the a-c voltage across the saturable reactor decreases, and the voltage across the capacitor C_1 increases as shown by the dotted vectors. The voltage E_3 on the transformer advances from E_3 to E_3' and consequently the ignitor firing advances. The voltage drops across the resistances R_1 and R_2 are neglected to simplify the diagram. In this firing circuit the arc is maintained for about 25 degrees. The advantages of this circuit over the one shown in Figure 2 are that the power consumed is less and the apparatus is smaller.

Figure 4 shows still another type of excitation circuit which shortens up the period over which the arc is maintained to about 18 degrees. This reduces the power drawn by the circuit still further, being only about 200 watts per ignitor. A modification of the autotransformer similar to Figure 3b will provide for insulated cathodes. The phase-shifting network consists of a saturable reactor X_s, a linear reactor X_L, and a capacitor C_1.

The vector diagram shows how the voltage E_3 varies in phase, with substantially constant amplitude as the voltage vector E_2, which is the a-c voltage across the saturable reactor, is changed in amplitude by means of the d-c saturating winding. The angle of firing of the ignitors shifts with the angle of the vector E_3.

Figure 4c shows the current in the nonlinear reactor, the voltage impressed on the ignitor, and the supply voltage.

Sometimes it is desirable to operate the main anodes of two ignitrons in parallel, and in that case the ignitors must be fired simultaneously in order that the main anodes will divide the current equally. This is best accomplished by firing four ignitors from one ignitor excitation circuit as shown in Figure 5. The current dividing autotransformer T_3 causes the two ignitors connected to the ends of the same transformer to be fired practically simultaneously. If the other transformers, reactors, resistors, and capacitors in the excitation circuit are built for the same voltage, but twice the current rating, we will have a circuit that is twice the size in kilovolt-ampere rating and will draw twice as much current and power from the line to fire twice as many ignitors. However, it has been found that the peak volt-amperes that this circuit is capable of delivering to a hard firing ignitor have been practically doubled. There is therefore a distinct advantage when operating ignitrons in parallel in firing their ignitors by this arrangement.

In order that various kinds of ignitor excitation circuits can be compared, it is necessary to have some way of measuring the peak voltage and current that the circuit is capable of delivering to the ignitor. In a circuit designed to use relieving anodes a variable resistance is connected in series with one ignitor between the ignitor and the blocking rectifier. In case the circuit is designed to operate without relieving anodes, a relieving anode should be used during this test connected as shown in Figure 6. This variable resistance can then be considered as being part of the ignitor, and the two together represent a high-resistance ignitor. The amount of current required to fire the ignitor can be varied by changing the depth of immersion of the ignitor in the cathode. With deep immersion a high current is required, and with shallow immersion a low current. For each different ignitor immersion depth, the resistance R is increased to such a value

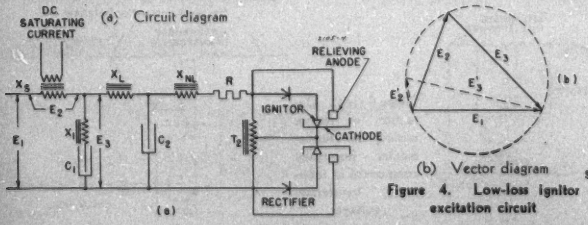
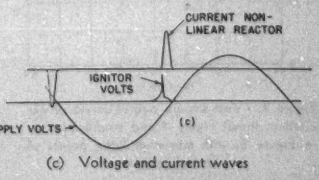


Figure 4. Low-loss ignitor excitation circuit



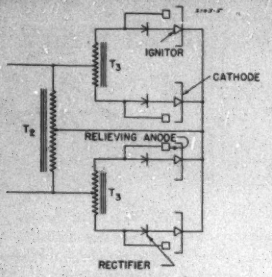


Figure 5. Method of firing two ignitors in parallel

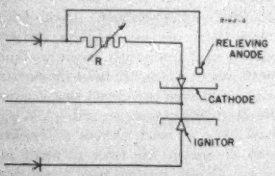


Figure 6. Circuit for measuring output of excitation circuit

that the ignitor misfires occasionally. With this setting the peak voltage across the resistance and ignitor is measured during a misfire. This is the peak voltage the circuit is capable of delivering simultaneously with the peak current. The peak current is determined from the voltage across *R*. A curve can then be plotted showing the peak current and the peak voltage the circuit is capable of delivering to the ignitor. Such curves are shown in Figure 7. A circuit test made by substituting a resistance for the ignitors can give misleading results, because a resistance does not have the nonlinear characteristic of an ignitor at the instant of firing.

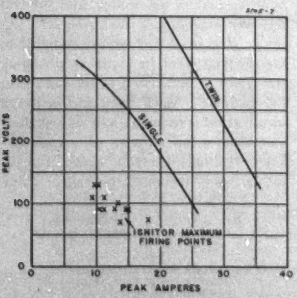


Figure 7. Volt-ampere output curves of excitation circuit Figure 4 and modification as in Figure 5, with maximum firing points of typical ignitors

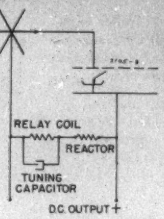


Figure 8 (left). Detection of ignitor misfire by fundamental - frequency component in d-c ripple

Figure 7 shows the peak volts and amperes that a typical circuit as in Figure 4 is capable of delivering to the ignitors. The curve labelled "single" is for the circuit as shown in Figure 4 and the curve labelled "twin" is for the circuit in Figure 4 when modified according to Figure 5 and using apparatus with twice the current rating. The points indicated by crosses in Figure 7 represent maximum peak voltage and current to fire typical ignitors. This shows that the circuit is putting ample power into the ignitors.

Detection of Excitation Failure

During operation of an ignitron rectifier one or more anodes may fail to conduct, due to a fault in the ignitor firing circuit or in one of the ignitors. Failure may be occasional or persistent.

Persistent misfire of one anode in a rectifier where two anodes are operating in parallel results in increased load being carried by the companion anode with a corresponding increase in arcback probability. In other circuits misfire of an anode may result in increased duty on one or more of the other anodes, with

1. Corresponding greater arcback probability.
2. Increase in transformer heating.

In any case, an indication of faulty operation is desirable, so that the fault may be remedied and normal operation continue.

Excitation failure may be detected by:

1. Action of the power circuit.
2. Action of the excitation circuit.
3. Action of auxiliary electrodes in the rectifier.

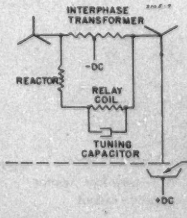


Figure 9 (left). Detection of ignitor misfire by fundamental - frequency component in interphase transformer voltage

I. Detection of Excitation Failure by Action of the Power Circuit

1. If one anode of a rectifier fails to fire, there will be a component of supply frequency in the d-c voltage ripple. The magnitude of this component will depend on the number of phases of the rectifier and the nature of the load. A relay connected to the d-c output voltage and having its coil tuned to the supply frequency will indicate misfire. This circuit is shown in Figure 8. A variation of this arrangement is to connect the tuned relay across a d-c reactor in series with the load. Either arrangement is most effective when the number of phases is small, and the d-c load is fairly reactive.

2. When an interphase transformer is included in the rectifier circuit, a voltage component of supply frequency occurs across the interphase transformer during misfire. A relay or other indicating device tuned to the supply frequency and connected across the interphase transformer will indicate the presence of a missing anode. The connections are shown in Figure 9. In a quadruple-wye circuit, an induction relay with two tuned coils may be used, each coil being connected to one of the 180-cycle interphase transformers.

3. Figure 10 shows a circuit which utilizes the increased positive voltage between anode and cathode, when the anode does not fire. This arrangement is most suitable for rectifiers operating without phase retard.

4. Figure 11 shows a circuit where unbalance between the neutral currents of a double-wye rectifier saturates a reactor and decreases its impedance.

5. Missing of an anode in one wye of a double-wye rectifier generally results in a disproportionate decrease of current in the other anodes of that wye. This is the basis of the circuit in Figure 12, which is affected by the difference between anode currents in the two wyes.

6. The missing of one anode will result in unequal currents in the supply line. This

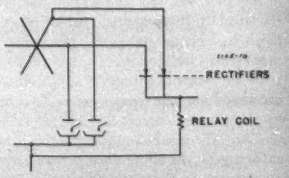
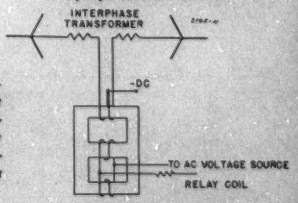


Figure 10. Detection of ignitor misfire by positive voltage of missing anode

Figure 11 (below). Detection of ignitor misfire by wye-current unbalance



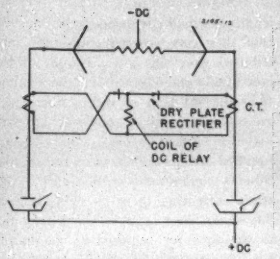


Figure 12. Detection of ignitor misfire by anode-current unbalance

may be recognized by visual observation of line ammeters or by a negative-phase-sequence relay. Operation of a double-wye rectifier circuit on five anodes results in a large negative-phase-sequence second harmonic component, due to the unbalance between the two secondary wyes. A negative-phase-sequence relay is less useful for misfire detection as the number of phases is increased.

7. When two anodes are operated in parallel from the same transformer winding, it is possible to utilize the current-dividing reactor, if one be used, as an indicator of misfire. Failure of an anode to fire would result in a much higher voltage than normal across the current-dividing reactor. This voltage may be utilized to operate an indicating device. Another method of using the current-dividing reactor is to design the reactor so that the core acts as the magnet of a relay and design the relay structure so that there will be sufficient flux to attract the armature only when the unbalance between the anode currents corresponds to misfire of one anode at 50 per cent or more load on the rectifier. Figure 13 is a photograph of such a reactor.

8. Another method of detecting misfire in the case of parallel anodes is to connect in each anode lead a current transformer designed to permit open circuit operation. If the secondaries are connected in opposition, there will be no voltage when both anodes fire, but a resultant voltage if one is missing. This may be used to operate a suitable relay. The resultant voltage will be present if all the pairs of oppositely connected secondaries are joined in series.

It should be noted that the above schemes for detecting missing of one of a pair of parallel anodes will not detect simultaneous missing of both anodes. Such missing will require one of the previously described circuits.

9. When a rectifier is carrying a steady load, as in electrolytic processes, and anodes are not operated in parallel, missing of an ignitor may be detected by observation of the d-c ammeter in the output circuit of the rectifier. This will show a distinct flicker each time misfire occurs. The anode transformer also gives an audible indication of misfire.

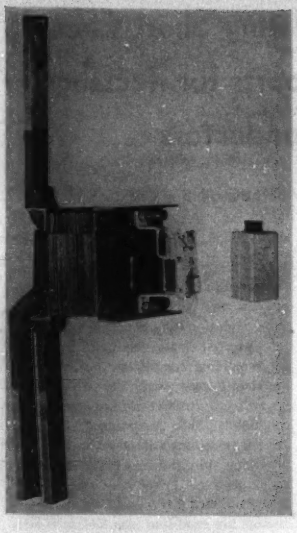


Figure 13. Combined current-dividing reactor and misfire-detection relay

II. Detection of Excitation Failure by Action of the Excitation Circuit

Failure of an element of the excitation circuit may result in one of a number of conditions, depending upon the nature of the failure. Since the ultimate purpose of failure detection is to determine if an ignitor is missing, the preferred location of a misfire device is in the circuit of the ignitor itself. Such a device becomes involved as it must function during

1. Ignitor short circuit.
2. Ignitor open circuit.
3. Insufficient power to fire ignitor.

Moreover, there must be one such device for each ignitor. Action of some other circuit than the excitation circuit appears desirable for misfire detection.

III. Detection of Excitation Failure by Action of Auxiliary Electrodes in the Rectifiers

The ignitron rectifier cell usually has an anode baffle which is excited from a different source than the other electrodes. Since current cannot flow in the baffle circuit unless a cathode spot is formed, current indicating means in series with the baffle or voltage indicating means across the baffle resistor will detect misfire.

Location of Missing Ignitor

With the exception of the scheme just described for indicating the presence of baffle current, the above misfire indication circuits do not indicate the specific ignitor which is misfiring. If an oscilloscope is at hand, missing may be located by observation of ignitor voltage. A clampon or tong ammeter may be used to detect current in the main anode. If a low-reading tong ammeter is available, it may be used to measure the current in the baffle. A compass held near an anode bus will show when an anode is not firing.

Conclusion

Static magnetic-impulse excitation circuits have definite advantages in many applications of ignitron rectifiers. Three circuits which have been described have different modes of operation, and their choice is determined by operating requirements. Excitation circuits are generally designed with an ample margin of power over ignitor requirements and in twin circuits for parallel operation. This margin is automatically increased for hard-firing ignitors.

An ignitor may stop firing even with ample excitation power. This condition may be detected in a number of ways. A choice of methods is available for specific applications.

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2. A New Ignitron Firing Circuit, H. Klemperer. *Electronics*, December 1939.

Formulas for Calculating Short-Circuit Stresses for Bus Supports for Rectangular Tubular Conductors

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ASSOCIATE AIEE

THE mechanical forces acting on bus-bar supports during short circuit are determined in some measure by all of the following:

The magnitude and decrement factor of the short-circuit current.

The mutual electromagnetic forces exerted among the individual conductors.

The natural frequencies, motional resistance, and physical arrangement of the bus-bar structures.

A theoretical treatment, substantiated by experimental data, of the individual and collective effects of these factors on the magnitude of bus-bar support stresses and a method of calculating numerically these effects are to be found in a comprehensive paper by Schurig and Sayre.[1] In shorter articles based on the just mentioned paper Schurig, Frick and Sayre,[2] Tanberg,[3] and Specht[4] have presented certain charts, nomograms, and short-cut methods facilitating the numerical calculations involved in an actual problem. However, regardless of the method of calculation adopted, a determination of bus-bar support stress yet requires calculation of the electromagnetic forces exerted on the conductors carried on the support.

The mutual electromagnetic force exerted between two isolated, long nonpermeable conductors, spaced D inches between their parallel axes and carrying direct currents of I and I' amperes, is commonly calculated from the formula

$$f = (5.4kII'/D)10^{-7} \text{ pounds per foot of bus length} \quad (1)$$

or, if absolute units are used, from

$$f = 2kII'/D \text{ dynes per centimeter of bus length} \quad (2)$$

Herein k is a parameter, a variously named constant, of magnitude determined by the geometry and relative position of the two conductor cross sections. In a group of conductors the force acting on any one conductor is calculated by using equation 1 to compute in turn the force exerted on the conductor by each of the remaining conductors and then adding these forces vectorially. If alternating instead of direct currents flow in the conductors, then providing f, I, and I' are taken as instantaneous values, and providing skin and proximity effects are negligible—this latter condition is commonly satisfied if rectangular tubular conductors are used and is sufficiently satisfied for strap conductors if, as is usual, the bus bar considered is either a single nonlaminated strap or is constructed of properly transposed laminated conductors—equation 1 is yet used, and k is the same as for direct currents. Accordingly, simple arithmetic aside, determination of the *electromagnetic* force acting on a given support reduces, in essence, to determination of the needed values of k.

Of essential interest to the designer of polyphase bus structures are the values of k for a group of identical conductors of solid or tubular rectangular cross section with axes in a plane. The formula for k for conductors of *solid* rectangular cross section was derived a quarter of a century ago; as regards rectangular tubular conductors, no formula for k seems to have been published hitherto. Yet as the mechanical and electrical advantages stemming from use of this cross section have resulted in an extensive and currently increasing use of it for feeding heavy current loads—to be noted in particular is its use in new bus installations supplying batteries of welders (in airplane, tank, and automobile factories) and banks of electric furnaces (for alloy and tool steels, aluminum, and various other metals) necessitated by the defense program—it is most desirable to have formulas with which one can quickly calculate the value of k for any conductor spacing or rectangular cross section. Such formulas are derived in this paper.

It is assumed that the conductors are nonmagnetic, right-cornered, and of such length that end effects are negligible, and that they carry currents uniformly distributed over the cross sections of the individual conductors. Of these assumptions all but that of right-corneredness are consistent with or are closely approximated in current practice. But although rounded corners are found on rectangular tubular conductors—to minimize "edge effect"—treating them as right-cornered introduces error negligible with reference to the accuracy required in calculating bus-bar stresses and enables solution of an otherwise intractable problem.

As regards values of k for strap conductors (which usually have right corners), the formulas derived in this paper—a strap conductor is a special case of a rectangular tubular conductor—offer an attractive alternative to the means of determination now used: curves, found in the references previously cited and in most electrical handbooks, these being plotted originally by Professor H. B. Dwight[5] from the above-mentioned formula derived by him. It is illustrated in section III that from equations 17 or 18 one can calculate rapidly, with but *pencil* or *slide rule*, the value of k for two symmetrically located, identical strap conductors.

The mentioned formulas for solid and tubular rectangular conductors obtained, ease and rapidity of use are illustrated by the numerical solution of several problems typical of bus design.

I. The Formal Solution for k

As derived in a previous paper by the writer,[6] the electromagnetic energy associated with a unit length of an isolated circuit constructed of two identical rectangular tubular conductors, symmetrically located as in Figure 1, is

$$W = w^2[W(r, s) + W(R, S) + 2W(t, S+t) + 2W(R+t, t) - 2W(R+t, S+t) - 2W(t, t)] \quad (3)$$

where, typically, $W(r, s)$ is defined by

$$W(r, s) = (1/6)[2F(D, s) - F(D+r, s) - F(D-r, s) + 2F(r, s) - 2F(0, s) + 4rs^2(3D-r)] \quad (4)$$

and, typically, $F(r, s)$ is defined by

$$F(r, s) = (r^4 - 6r^2s^2 + s^4) \log (r^2+s^2)^{1/2} + 4rs(r^2 - s^2) \tan^{-1}(r/s) - r^4 \log |r| \quad (5)$$

All units are in the absolute system: the current density w in abamperes per square centimeter; D, r, and s in centimeters; W in ergs per centimeter of line length.

As is well-known, the mutual electro-

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magnetic force exerted between the two conductors is given by

$$f = \partial W/\partial D \text{ dynes per centimeter of bus length} \quad (6)$$

Equating equations 2 and 6 and solving for k yields

$$w^2 k = [D/2(rs - RS)^2]\partial W/\partial D \quad (7)$$

Substituting equation 3 in equation 7 gives

$$k = [D/2(rs-RS)^2]\left[\frac{\partial W(r,s)}{\partial D} + \frac{\partial W(R,S)}{\partial D} + 2\frac{\partial W(t,S+t)}{\partial D} + 2\frac{\partial W(R+t,t)}{\partial D} - 2\frac{\partial W(R+t,S+t)}{\partial D} - 2\frac{\partial W(t,t)}{\partial D}\right] \quad (8)$$

From equation 4 we have

$$\frac{\partial W(r,s)}{\partial D} = (1/6)\left[\frac{\partial}{\partial D}\{2F(D,s) - F(D+r,s) - F(D-r,s)\} + 12\pi r^2 s\right] \quad (9)$$

The bracketed expression in equation 9, considered as a function of r alone, can be expanded in a power series about the point $r = D$. Substituting this expansion in equation 9 we have

$$\frac{\partial W(r,s)}{\partial D} = (1/6)\left[\frac{\partial}{\partial D}\left\{-r^2\frac{\partial^2 F(D,s)}{\partial D^2} - \frac{r^4}{2\cdot 3!}\frac{\partial^4 F(D,s)}{\partial D^4} - \frac{r^6}{3\cdot 5!}\frac{\partial^6 F(D,s)}{\partial D^6} - \cdots\right\} + 12\pi r^2 s\right]$$

$$= (1/6)\left[-r^2\frac{\partial^2 F(D,s)}{\partial D^2} - \frac{r^4}{2\cdot 3!}\frac{\partial^4 F(D,s)}{\partial D^4} - \frac{r^6}{3\cdot 5!}\frac{\partial^6 F(D,s)}{\partial D^6} - \cdots + 12\pi r^2 s\right] \quad (10)$$

The details of the expansion and expressions for the various derivatives, in terms of the dimensions and spacing of the conductors, are given in the appendix. Substituting appropriately in equation 10 and collecting terms, we have

$$\frac{\partial W(r,s)}{\partial D} = 2r^2\left[[2s\tan^{-1}(s/D) - D\log\left(1+\frac{s^2}{D^2}\right)\right] + \frac{r^4}{3}\frac{s^2}{D(D^2+s^2)} + \frac{r^6}{45}\left[\frac{1}{D^2} + \frac{-D^2+3Ds^2}{(D^2+s^2)^2}\right] + \cdots = 2DM(r,s) \quad (11)$$

where $M(r,s)$ is defined by

$$M(r,s)/r^3 = 2m\tan^{-1}m - \log(1+m^2) + \frac{n^2m^2}{6(1+m^2)} + \frac{n^4}{90}\left[1+\frac{-1+3m^2}{(1+m^2)^2}\right] \quad (12)$$

where $m = s/D$ and $n = r/D$.

Substituting equation 11 in equation 8 yields

$$k = [D^2/(rs-RS)^2][M(r,s) + M(R,S) + 2M(t,S+t) + 2M(R+t,t) - 2M(R+t,S+t) - 2M(t,t)] \quad (13)$$

If $R = S = t = 0$, we have solid rectangular conductors, and equation 13 becomes

$$k = (1/m^2r^3)M(r,s) \quad (14)$$

Having determined k—note that k is a dimensionless quantity; thus D, r, and s can be measured in any unit of length—the electromagnetic force f can be determined from equation 1.

II. Approximate Expressions for M(r, s)

In most calculations the conductor cross sections and spacing are such that in equation 11 the terms involving powers of n are negligible. If so, equation 12 reduces to

$$M(r,s)/r^3 = 2m\tan^{-1}m - \log(1+m^2) \quad (15)$$

Although equation 15 can be calculated directly by the aid of appropriate tables or by use of a slide rule, it is more desirable to have $M(r,s)/r^3$ expressed directly in powers of m. Accordingly, substituting in equation 15, the usual power series for $\tan^{-1}m$ and for $\log(1+m^2)$ and collecting terms, we have the more desirable form

$$M(r,s)/r^3 = m^2 - m^4/2\cdot 3 + m^6/3\cdot 5 - m^8/4\cdot 7 + \cdots \quad (16)$$

where $m < 1$.

Substituting equation 16 in equation 14 we have for solid conductors

$$k = 1 - m^2/2\cdot 3 + m^4/3\cdot 5 - m^6/4\cdot 7 + \cdots \quad (17)$$

where $m < 1$.

Occasionally, in equation 12 the term in n^2 is not negligible in comparison with the first two terms. In this case, expanding $(1+m^2)^{-1}$ in powers of m and adding to equation 16 we have

$$M(r,s)/r^3 = m^2\left(1+\frac{n^2}{6}\right) - m^4\left(\frac{1}{6}+\frac{n^2}{6}\right) + m^6\left(\frac{1}{15}+\frac{n^2}{6}\right) - \cdots \quad (18)$$

where $m < 1$.

III. Some Illustrative Examples

EXAMPLE 1

Conductors a, b, c of a three-phase bus are of four- by one-half-inch strap, spaced six inches between adjacent axes, with four-inch edges perpendicular to the plane of axes. To calculate k for conductors a and b, and for conductors a and c.

Part A. $D = 6$ inches; $r = 0.5$ inch; $s = 4$ inches; $n = 0.5/6 = 1/12$; $m = 2/3$. From equation 12 for the terms taken in order

$$M(r,s)/r^3 = (4/3)\tan^{-1}(2/3) - \log(13/9) + 1/2808 + \cdots = 0.7840 - 0.3677 + 0.0004 = 0.4167$$

Accordingly, from equation 14

$$k = (9/4)(0.4167) = 0.938$$

For comparison, we have from equation 17

$$k = 1 - 4/54 + 16/(81)(15) - 64/(729)(28) + 256/(6561)(45) - \cdots = 1 - 0.0741 + 0.0132 - 0.0031 + 0.0009 = 0.937$$

Part B. $D = 12$ inches; $r = 0.5$ inch; $s = 4$ inches; $n = 0.5/12 = 1/24$; $m = 1/3$. As n and m are smaller even than in part A, k is best calculated directly from equation 17.

$$k = 1 - 1/54 + 1/(81)(15) - 1/(729)(28) + \cdots = 1 - 0.0185 + 0.008 = 0.982$$

These two values of k computed from equation 17—with a ten-inch slide rule and with purposely exaggerated accuracy—indicate the rapidity with which this expression yields values of k for str. p conductors. As in practice but the first two digits are used in actual computations, but the first two or three terms in equation 17 need normally be calculated.

EXAMPLE 2

Conductors a, b, c of a three-phase bus are 2.5- by 2.5-inch square tubular conductors, 0.5 inch thick, spaced 10 inches between adjacent axes. To calculate k for conductors a and b

$D = 10$ inches; $r = s = 2.5$ inches; $R = S = 1.5$ inches; $t = 0.5$ inch. For the data given we have from equation 13

$$k = (100/16)[M(2.5,2.5) + M(1.5,1.5) + 2M(0.5,2) + 2M(2,0.5) - 2M(2,2) - 2M(0.5,0.5)] \quad (19)$$

To determine k each of the terms of equation 19 must be calculated. From equation 18 we have for the terms taken in order

$$M(2.5,2.5) = 6.25(0.063151 - 0.000692 + 0.000019) = 0.39049$$
$$M(1.5,1.5) = 2.25(0.022584 - 0.000086) = 0.05062$$
$$M(0.5,2) = 0.25(0.040017 - 0.000267 + 0.000004) = 0.00994$$
$$M(2,0.5) = 4.00(0.002517 - 0.000001) = 0.01006$$
$$M(2,2) = 4.00(0.040267 - 0.000277) = 0.15996$$
$$M(0.5,0.5) = 0.25(0.002501 - 0.000001) = 0.00063$$

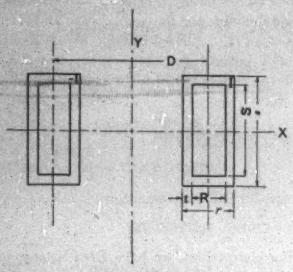

Figure 1. Rectangular tubular conductors symmetrically located

Substituting these values in equation 19 we have for k

$$k = (100/16)[0.39049 + 0.05062 + 0.01988 + 0.02012 - 0.31992 - 0.00126] = 0.999+$$

This example is of particular interest, as, in addition to illustrating the method of calculating k for rectangular tubular conductors, it reveals that for *square tubular conductors*—and these are commonly used—*the value of k for practical conductor spacings is unity*. If the conductors are rectangular with long sides perpendicular to the plane of axes, k will be less than unity; and if the short sides are perpendicular to the plane of axes, k will be greater than unity: in either case k can be calculated as above.

Appendix

Considered as a function of r alone

$$F = 2F(D, s) - F(D+r, s) - F(D-r, s)$$

can be expanded in a power series about the point $r = D$. Accordingly, by Taylor's theorem we have

$$F = -r^2\frac{\partial^2 F(D, s)}{\partial D^2} - \frac{r^4}{2 \cdot 3!}\frac{\partial^4 F(D, s)}{\partial D^4} - \frac{r^6}{3 \cdot 5!}\frac{\partial^6 F(D, s)}{\partial D^6} - \cdots$$

where

$$F(D, s) = \tfrac{1}{2}(D^4 - 6D^2s^2 + s^4)\log(D^2+s^2) - D^4 \log D + 4(sD^2 - Ds^2)\tan^{-1}(D/s)$$

$$\frac{\partial F(D, s)}{\partial D} = (2D^3 - 6Ds^2)\log(D^2+s^2) - 4D^3 \log D + 4(3sD^2 - s^3)\tan^{-1}(D/s) - 3Ds^2$$

$$\frac{\partial^2 F(D, s)}{\partial D^2} = 6(D^2 - s^2)\log(D^2+s^2) - 12D^2 \log D + 24Ds\tan^{-1}(D/s) - 7s^2$$

$$\frac{\partial^3 F(D, s)}{\partial D^3} = 12D\log(D^2+s^2) - 24D\log D + 24s\tan^{-1}\times(D/s) = 12D\log(D^2+s^2)/D^2 - 24s\times\tan^{-1}(s/D) + 12\pi s$$

$$\frac{\partial^4 F(D, s)}{\partial D^4} = 12\log(D^2+s^2) - 24\log D$$

$$\frac{\partial^5 F(D, s)}{\partial D^5} = -\frac{24s^2}{D(D^2+s^2)}$$

$$\frac{\partial^6 F(D, s)}{\partial D^6} = 24\left[\frac{1}{D^2} - \frac{D^2 - s^2}{(D^2+s^2)^2}\right]$$

$$\frac{\partial^7 F(D, s)}{\partial D^7} = 48\left[-\frac{1}{D^3} - \frac{-D^2 + 3Ds^2}{(D^2+s^2)^3}\right]$$

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The Carbon Arc—a Valuable Industrial Tool

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FELLOW AIEE

Synopsis: The versatility of the carbon arc as a source of both visible and invisible radiation is shown to be due, in part, to the three basic types of operation to which it is adapted and also to the fact that the character of its energy emission can be modified by changes in core composition. It is used in its various forms for many photochemical and irradiation processes, some of which require specific bands of ultraviolet radiation or close reproduction of the effects of natural sunlight. The carbon arc is preferred in other instances, because the optical requirements of the application necessitate a light source of small area and extreme brilliancy. Several industrial and commercial uses are cited together with the characteristics which give preference to the carbon arc as a source of radiation.

THE present widespread industrial use of the carbon arc is due to certain characteristics or combination of characteristics in which it is superior to other available sources of artificial radiation. Capable of efficiently producing a large volume of light, the original commercial application of the carbon arc was in the field of general illumination. It has been used extensively for street lighting and for the illumination of factories, auditoriums, and other large areas. Its present value is due, in large measure, to its versatility as a source of invisible as well as visible radiation and extends into many fields other than those of general illumination. In some instances preferred solely for its visible radiation, the carbon arc is selected for other applications because of the character and intensity of its invisible rays, while the choice at times may be due to the combination of visible and invisible rays which it supplies.

Besides being a highly efficient source of radiant energy in the visible and adjacent invisible bands of radiation, the carbon arc is highly flexible in respect to quality of emission. This flexibility is due, in part, to the three basic types of operation to which the electric arc between carbon electrodes can be adapted:

1. Low-intensity operation between solid or "neutral-cored" electrodes.
2. Low-intensity operation between electrodes having cores containing flame-supporting materials.
3. High-intensity operation.

Distinguishing characteristics of these three types of arcs have been described in previously published articles.[1,2] Briefly, the low-intensity arc between solid or neutral-cored carbons is adapted to a relatively simple type of lamp mechanism. At high arc voltage it is a very efficient source of ultraviolet in the range from 3,700 to 4,000 angstroms. The positive crater of the d-c low-intensity arc provides a steady concentrated light of the greatest brilliancy and whiteness available from a purely incandescent source. With a peak brilliancy of 180 candles per square millimeter and an average color temperature of about 3,550 degrees Kelvin, this type of arc has been extensively used for searchlights and for motion-picture projection. It has yielded its dominant position in these fields only to the higher brilliancy, whiteness, and efficiency of the high-intensity carbon arc.

The low-intensity flame-type arc, with the greater portion of its radiation emanating from the long arc stream at a brilliancy on the order of eight candles per square millimeter, is not so well adapted as the other basic types of arcs to use with optical systems that require a light source of small area and very high brilliancy. However, due to the large area of the flame, this type of arc emits a large volume of radiation which is produced at high electrical efficiency. An important advantage of the flame arc is the wide range in quality of radiation that can be obtained by varying the composition of the core[3] and the uniformity in both quality and intensity of radiation obtained from a particular type of carbon, when operated at specified arc conditions. When cored with certain rare earth compounds, the flame arc produces radiation so similar to that of natural sunlight in spectral composition that for many applications its effects are practically identical with those of sunlight. This light is the closest approach to natural sunlight of any artificial source having sufficient intensity for numerous industrial applications. Other combinations of core materials provide high emission of infrared or ultraviolet and permit emphasis on specific bands of ultraviolet, corresponding to the wave lengths at which most rapid reaction is obtained in certain photochemical and irradiation processes.

The high-intensity carbon arc is characterized by its very high crater brilliancy, 350 to 1,200 candles per square millimeter, and—with the core composition used in all but certain high-intensity therapeutic carbons—by the even distribution of all colors in its spectrum. The crater brilliancy of 1,200 candles per square millimeter is obtained from a new positive carbon only recently made available for use. A brilliancy of 2,000 candles per square millimeter has been attained with an experimental type of carbon not yet available for commercial application. The appearance of the d-c high-intensity arc is illustrated in Figure 1. Color temperature of the light from high-intensity arcs used in motion-picture projection averages about 5,800 degrees Kelvin. Maintenance of the high-intensity effect is dependent on the position of the electrodes in relation to each other. This relationship is maintained by continuous and accurately controlled feeding of the electrodes, and, in some of the larger high-intensity arc lamps, the positive carbon

Figure 1. High-intensity carbon arc with rotating positive electrode

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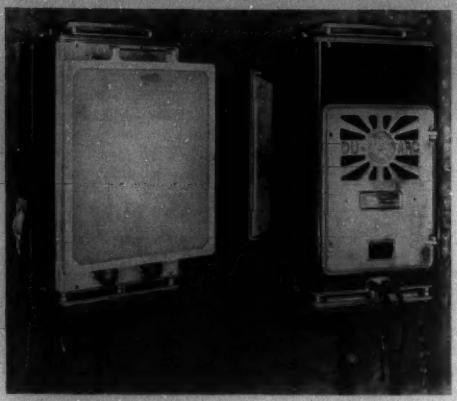

Figure 2. Twin-arc, motor - controlled lamp used for broadside lighting

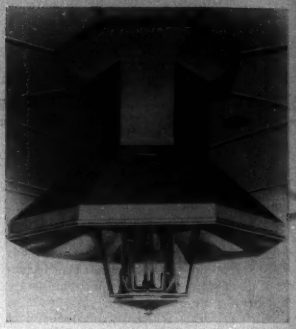

Figure 5. Four-arc carbon-arc solarium unit

is rotated, in order to maintain a symmetrical crater formation. The principal use of this highly concentrated source of illumination is for searchlights and for motion-picture production and projection.

Summarizing the advantages which give the carbon arc an important place in industry, the following points may be noted as available in one or more of the basic types:

1. Very high output of radiant energy from a single source.
2. Flexible quality of energy emission.
3. Close approximation to natural sunlight.
4. Uniform quality and intensity of emission at specified arc conditions.
5. Output unaffected by age or period of operation.
6. High intrinsic brilliancy, adapted to optical systems requiring a highly concentrated source of radiation.
7. Shape of light source and distribution of brilliancy adapted to simple optical systems.
8. High efficiency in production of both ultraviolet and visible radiation.

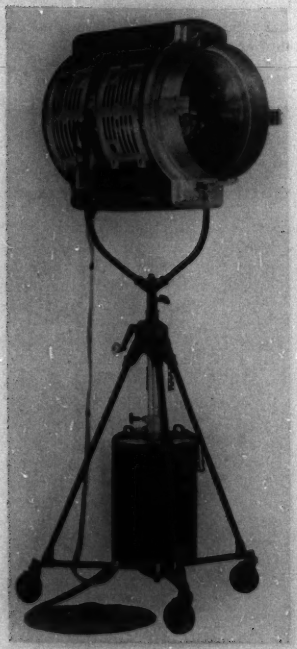

Figure 3. High-intensity carbon-arc lamp with Fresnel-type lens

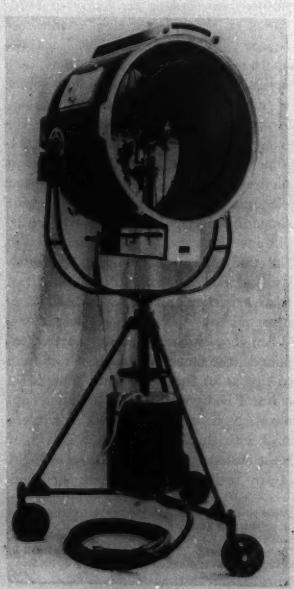

Figure 4. 36-inch sun arc

The carbon arc was adopted at an early date as an artificial source of illumination for photography and allied photochemical industrial processes, such as blueprinting, photoengraving and photolithography. High actinic power, color quality, and adaptability to high illumination intensities are among the major reasons carbon-arc lighting was adopted by these industries and are still major factors in the extension of its use. Early photographic emulsions, sensitive principally to blue, violet, and ultraviolet radiation, react rapidly to the light of the low-intensity arc. This was the only type of arc available when photographers first turned to artificial lighting. As the sensitivity of photographic emulsions was extended through green to yellow and orange wave lengths, the white-flame arc, by that time available, was adopted, because its higher output of visible radiation gave greater speed and better photographic quality than the neutral-cored carbon arc. With modern photographic emulsions, sensitive to all colors of the spectrum, the advantages of the even distribution of color in the light from the white-flame arc have been further emphasized.

The high photographic speed of the white-flame carbon arc and its similarity to daylight made it the preferred artificial light source for photoengraving and photolithography, even when production in these industries was predominantly monochromatic. The growing popularity of natural-color reproduction in the graphic arts emphasizes the value of a light which provides all of the spectral

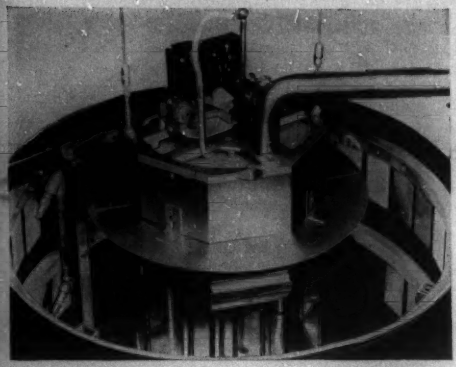

Figure 6. Interior of carbon-arc accelerated-weathering unit

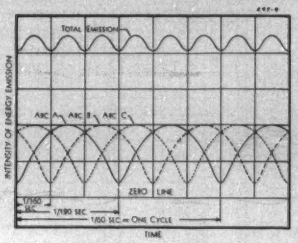

Figure 9. Energy emission from three-phase 60-cycle flame arc

colors at essentially equal intensity. High-intensity arcs are used in photolithography for large-sized reproduction by the projection method.

The motion-picture studios depend chiefly on carbon-arc lighting for natural-color photography. This also is due to the need for an even balance of the primary colors. The color balance of the light from carbon arcs, as adapted to studio use, conforms so closely to that of sunlight that the two are considered essentially equivalent for photographic purposes. The type of lamp generally used for broadside lighting is shown in Figure 2. This lamp has a motor-driven feeding mechanism which maintains very steady light output and is extremely quiet, permitting operation in proximity to the microphone without difficulty. It uses a special white-flame carbon producing light with a color temperature of 4,650 degrees Kelvin almost perfectly balanced to the color sensitivity of motion-picture film, and requiring no color-correcting filter.

High-intensity arc lamps equipped with a Fresnel-type lens, as illustrated in Figure 3, are used for back lighting, cross lighting and key lighting and for both wide and narrow beam front and effect lighting. High-intensity "sun arcs," with 24-inch and 36-inch mirrors, Figure 4, are used for extremely long throws, for sharply outlined shadows, or to provide a clearly defined beam of light through the general illumination. Because of their ready adaptability to the needs of the studio and to modern photographic technique, many cinematographers are using carbon arcs as the principal source of illumination for monochromatic as well as for color productions.

For background projection or process photography a light source of tremendous power is required to project the background scene through the screen at an intensity comparable to that of the lighting on the set. Only the high-intensity carbon arc has sufficient power for this purpose. In fact, three background projectors are sometimes used, synchronized with each other and with the camera, each projecting the same scene in exact register through the screen. The precision of mechanism and optical elements which has made possible this intricate projection system is a major engineering accomplishment.

The high-intensity carbon arc is an ideal light source for searchlights, because its tremendous output is concentrated in a very small area. This permits the light

Figure 7 (left). Carbon-arc accelerated-fading unit

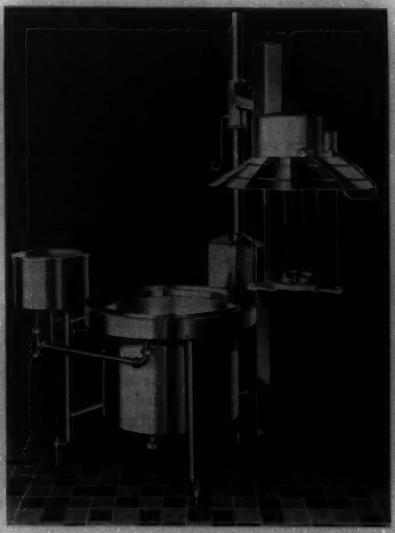

Figure 8 (right). Three-phase carbon-arc milk-irradiating unit—open

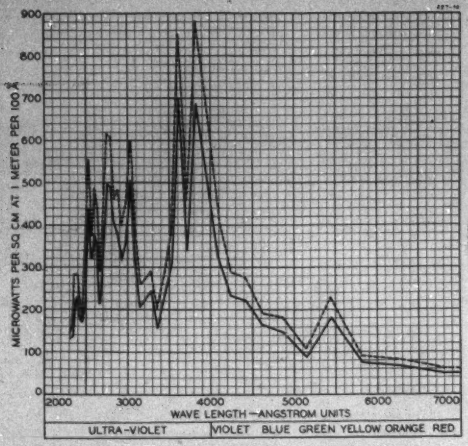

Figure 10. Distribution of radiant energy from flame arc used in milk irradiation

Dotted curve—At 80 amperes, 60 volts, a-c
Solid curve—At 80 amperes, 50 volts, a-c

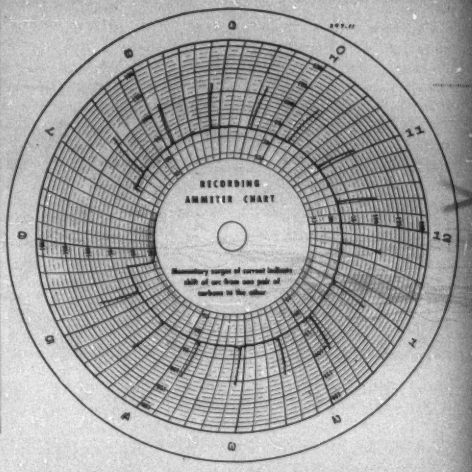

Figure 11. Recording-ammeter chart from unit shown in Figure 6

to be focused by the lens or reflector of the searchlight into a beam of small divergence and high penetration. The high-intensity searchlight with 16-millimeter positive carbon, operated at 150 amperes and 78 volts, and using a 36-inch reflector, projects a beam of considerably more than 100-million beam candle power and, with a 60-inch reflector, the beam candle power is well over 500 million. At 195 amperes and 84 arc volts the beam candle power is 30 to 50 per cent higher than at 150 amperes. Exact candle power of the beam is dependent on shadow losses, glass absorption, and the optical characteristics and reflection factor of the mirror.

Carbon arcs were used for motion-picture projection from the earliest days of the industry and are in practically universal use for theater projection today. No other commercially available light source provides light of suitable power, concentration, and color quality to meet the projection requirements of motion-picture theaters. The present trend is toward replacement of low-intensity projection lamps with high-intensity lamps of simplified design. This trend results from increasing recognition of the need for higher levels of illumination and also from popular demand for fidelity of color reproduction in the presentation of natural color features. Approximately 50 per cent of the light from the low-intensity carbon arc is in the orange and red portion of the spectrum. This color composition overemphasizes the red components in color pictures. Theatrical film of this type is processed for projection with light having approximately equal intensities of the three primary colors, a condition which the high-intensity arc fulfills most acceptably. The development of high-intensity projection lamps which require little more than one kilowatt at the arc has put the cost of high-intensity projection light essentially on the same level as that of low-intensity light, and has made it available to theaters which could not previously afford to operate high-intensity lamps. Other applications of the carbon arc for projection purposes include stereopticon projectors, spotlights, and theatrical "effect" lighting.

Since the discovery by Finsen that radiation from the carbon arc provides a cure for certain physical disorders, carbon-arc lamps have been extensively used in light therapy. The flame-type carbon arc is at present preferred for this purpose, because of its versatility in respect to quality of radiation. With one type of carbon close simulation of the physiological effects of sunlight is obtained. Other types give powerful emission in specific bands of ultraviolet. Still another type has mild ultraviolet emission, combined with a high output of penetrating radiation of longer wave length. All of these carbons can be burned in the same lamp. A large carbon-arc solarium unit, such as that illustrated in Figure 5, provides radiation of suitable intensity for light therapy over a circle of 20 standard solarium cots.

The increasing importance of quickly determining the resistance of various materials to deterioration under the action of sunlight has resulted in the almost universal adoption of the carbon arc as the source of radiation in accelerated testing units. This, again, is due to the fact that the quality of radiation delivered and the resulting effects are comparable to those of natural sunlight. Furthermore, radiation can be provided at an intensity which greatly accelerates the rate of deterioration and, being available 24 hours a day at constant intensity every day of the year, allows conclusive evidence of product quality to be obtained in much less time than is possible by means of outdoor tests.

In accelerated weathering units, such as that illustrated in Figure 6, test samples are carried on a rack which revolves slowly around the arc. At a portion of their revolution the samples are exposed to a water spray. The weathering action of water, air, thermal shock, and radiation of sunlight quality are thus combined in one test, the conditions of which can be exactly reproduced at any time and in any location. The unit illustrated employs a 60-ampere, 50-volt single-phase, a-c flame arc operated through a transformer from a 230-volt line. There are two upper and two lower carbons, but the arc burns between only one pair at a time. This unit accommodates 64 samples at one time. Paints, lacquers, enamels, varnishes, plastics, rubber and rubberlike materials, roofing and building materials, materials for leggings, tents, and tarpaulins, and special types of glass are included in the list of products for which accelerated test-

ing is now a standardized procedure. Comparative records made by users of these units indicate that an exposure of 30 hours in the unit described is approximately equivalent to one month of outdoor exposure.

Units designed for comparing the color fastness of dyes, dyed fabrics, paper, plastics, and other products do not have the water spray that is provided in the weathering unit but usually have provision for maintaining an adjustable degree of humidity. The unit shown in Figure 7 has a 30-ampere, 40-volt, single-phase arc lamp, operated through a transformer from a 230-volt line. This lamp has three upper and three lower carbons, but the arc burns between only one pair at a time. This allows it to operate continuously for 24 hours without retrimming. The revolving rack carries 18 sample holders, curved to the mean radial distance of $10^{1}/_{4}$ inches from the arc.

Recognition of the dietary importance of vitamin D has led to extensive use of carbon-arc lamps as a source of ultraviolet for increasing the vitamin-D potency of milk. Several types of carbon-arc milk irradiators are in use, one of the most efficient of which employs a 12- to 14.4-kw, three-phase, carbon-arc lamp with 80 amperes and 50 to 60 volts at each arc. This unit is shown in open position in Figure 8. In operating position the lamp is centrally located within the large drum. Besides making available in small space a high intensity of radiant energy, the three-phase carbon arc insures a continuously high level of energy emission as illustrated in Figure 9. Ultraviolet, the activating agency, does not penetrate milk to appreciable depth, and portions of the rapidly flowing film of milk in an irradiator may reach the exposed surface only during low-emission portions of the energy cycle from a single-phase source. Experience has demonstrated that the effectiveness of the irradiation process is increased by maintaining a continuously high level of energy emission. Since the flame-type arc operates more efficiently on alternating than on direct current, due to the use of reactance instead of resistance ballast, the polyphase arc is the most practicable means of maintaining a high-emission level.

Some objection to the irradiation process for increasing vitamin-D potency of milk has resulted from the use of sources of ultraviolet which produce considerable ozone and result in impaired flavor. The carbon arc is free from this objection. Coltman and MacPherson[4] have shown, by a method of spectroscopic analysis capable of clearly detecting 14 parts per hundred million, that no ozone above that concentration is present in the gases surrounding the carbon arc. Furthermore, producers of both fluid and evaporated milk have found that a vitamin-D potency of 400 USP units per quart can be obtained by carbon-arc irradiation without impairing the natural flavor of the milk.

Figure 10 shows the distribution of radiant energy from the type of flame carbon found most effective for milk irradiation. With these carbons the unit shown in Figure 8 is capable of activating 8,000 to 10,000 pounds of fluid milk per hour to a potency of 400 USP units per quart.

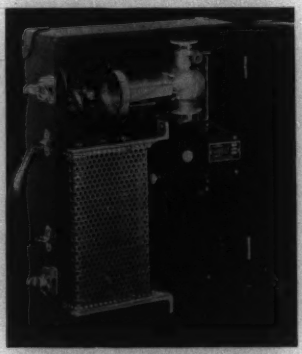

Figure 12. Portable ultraviolet carbon-arc lamp in carrying case

Uniformity of radiation from the large carbon-arc lamps used in the industrial testing and irradiating units here described is obtained by a motor-driven carbon feeding mechanism which provides automatic control of arc current. Accuracy of control has been greatly improved by the use of a 96-pole, 75-rpm reversible synchronous motor to drive the feeding mechanism. Because of its slow speed the rotor of this motor has little momentum and does not have the tendency to overrun, after opening of the motor-control relay, which is characteristic of high-speed motors. Hunting is thereby practically eliminated. Steadiness of arc-current control realized in practice is shown by the recording ammeter chart from an accelerated weathering unit reproduced in Figure 11. The momentary peaks at approximately 40-minute intervals indicate the shift of the arc from one pair of electrodes of the dual carbon trim to the other.

The applications of the carbon arc which have been cited are representative of the more extensive uses of this versatile source of radiation for industrial purposes. Carbon-arc lamps are used also to provide light of daylight quality, closely controlled in color composition and intensity, for critical matching of color. Ultraviolet radiation from carbon arcs is used in the processing of tobacco and other commercial products and in the preparation of certain pharmaceutical materials. Spectroscopic carbon and graphite electrodes of very high purity are used for spectroscopic analysis and as a source of radiation of reproducible intensity and spectral energy distribution for high temperature calibration and for color standardization.[5] The ash content of these special electrodes is considerably below 0.001 per cent. A portable carbon-arc lamp fitted with ultraviolet filter, Figure 12, is used in both laboratory and field for fluorescence inspection and analysis. Many of these lamps are used in crime detection. Other important industrial applications of the carbon arc, entirely outside the field of illumination, are in electric welding and in electric arc furnaces used for a variety of electrochemical and electrometallurgical processes. Although no longer before the eye of the general public, as when carbon-arc lamps hung on every street corner, this source of radiant energy is today more widely used and of greater industrial value than at any time in the past, and further extension of its commercial and industrial applications may confidently be expected.

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A New Moving-Magnet Instrument for Direct Current

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Synopsis: A new type of d-c instrument is described in this paper. It comprises a diametrically magnetized cylindrical moving-magnet element, a hollow copper damping cylinder surrounding the moving element, a fixed coil, control magnets having a very high coercive force, and an enclosing magnetic shield made of mumetal. The field of the control magnet and the field of the fixed coil have a relatively large angular displacement. The angular position of the vector sum of these fields varies with the current through the coil, and the moving element follows this vector. The scale distribution is nearly uniform for a 90-degree scale. The characteristics compare favorably in many respects with those of a D'Arsonval instrument.

OERSTED'S discovery that a compass needle tends to set itself at right angles to a wire carrying an electric current provided the basis for the design of the first electromagnetic indicating instrument, which consisted of a coil of wire surrounding a magnetized needle.[1] This in turn led to the development of the astatic galvanometers of Nobili and Kelvin and of the sine and tangent forms of galvanometer. These latter instruments, which depended upon the earth's field for their control torques, were obviously unsuited for use as portable instruments.

Ayrton and Perry, in designing the first portable d-c ammeter, used a large permanent magnet to produce a controlling field. In this instrument the polarization of the vane was derived from the fixed permanent magnet rather than from its own permanent magnetism. Since the field of the control magnet had to be so strong that the earth's field was negligible by comparison, the field of the coil had to be correspondingly strong in order to deflect the vane. This made the sensitivity of the instrument inherently low, since so many ampere turns were required to excite the field. Modifications of the Ayrton–Perry instrument are used for automobile ammeters, and similar applications where low cost and ruggedness are important, and where sensitivity and high accuracy are not required.

The principle of the permanent-magnet moving-coil galvanometer as developed by Sturgeon, Kelvin, and D'Arsonval was used by Weston in the design of the first moving-coil portable instrument. This principle is now generally used in all d-c instruments of high accuracy and high sensitivity.

Development of New Moving-Magnet Design

Although highly sensitive suspended magnet instruments have been built, no portable moving-magnet instruments have come into general use. "Moving-magnet instrument" is here intended to denote an instrument in which the magnetomotive force of the moving element is much greater than that produced by the fixed coil or by the fixed control magnets.

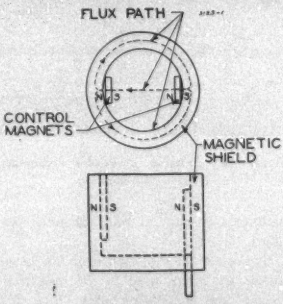

Figure 1. Path of control-magnet flux in magnetic shield

In an instrument of high sensitivity, the field of the fixed coil will be rather weak because of the small power available for producing it. This means that the instrument must be well shielded against stray fields which, even in the case of the earth's field, would be comparable in strength with the field produced by the instrument coil. This is accomplished by enclosing the moving magnet, coil, and control magnets in a cylindrical cup of magnetic material of high permeability and low coercive force. Permalloy or mumetal[2] are suitable materials for this shield.

Controlling torque may be obtained either from a magnet or from a spring. In this instrument a magnet was preferred because of ease of adjustment and other considerations. Since the control magnet must be placed within the shield, it must be very short in the direction of its magnetization and must have its magnetization unaltered by the field of the moving magnet. It is apparent that a material of very high coercive force is required. This requirement is met by an alloy of silver, aluminum, and manganese which was first described by Potter.[3,4] This alloy has a coercive force ($_{\mu}H_c$) of 6,000 oersteds and a residual induction of 610 gausses. It is unique among permanent-magnet materials in having a coercive force of this high value. The high coercive force enables the control magnets, which are in the form of thin strips, to be magnetized in the direction of their thickness. As shown in Figure 1, these magnets are mounted on opposite ends of a diameter inside the cup so as to produce a control field in the direction of this diameter. The strength of this field may be decreased or increased by inserting or withdrawing one magnet through a hole in the bottom of the shield as shown in the right-hand magnet in Figure 1. This adjusting motion is parallel to the axis of the cylinder and does not affect the direction of the control field in the plane in which the moving magnet turns. Thus, it controls the sensitivity without affecting the zero setting or the scale distribution of the instrument.

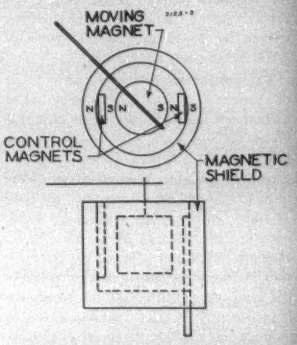

Figure 2. Relative positions of moving magnet, control magnets, magnetic shield, and pointer

The moving magnet should have a small moment of inertia in order to give good responsiveness and damping. At the

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same time it should provide a strong field in order to give as high torque as possible. Since the moving element must revolve through an arc of 90 degrees or more, the largest volume of permanent-magnet material can be put into a rotor which is bounded by a surface of revolution. From these considerations it appears that a cylindrical shape will be suitable for the moving magnet. A cylindrical magnet, magnetized along its diameter, has a very small ratio of length to cross-sectional area and, hence, should have a much larger ratio of coercive force to residual induction than that of any of the commonly known magnet steels. The silver alloy used in the control magnets does not have a sufficiently high residual induction for this application. A very good material is an oxide magnet made of a mixture of iron and cobalt oxides.[5] This material has a coercive force of approximately 950 oersteds, a residual induction of 2,200 gauses, and a $B \times H$ maximum value of

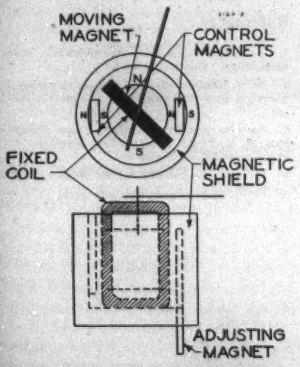

Figure 3. Diagram of complete moving-magnet-instrument element

approximately 10[6]. The specific gravity of this material is half that of steel. Since the factor of merit of an electrical instrument depends on the weight of the moving element, this material is equivalent to steel having twice this $B \times H$ maximum value. Figure 2 shows the cylindrical magnet mounted within the shield and control-magnet assembly.

The field of the moving magnet has no appreciable effect on the permanent magnetization of the control magnets, because their coercive force is so high as to require a much stronger field to magnetize or demagnetize them. The field of the control magnets is much weaker than that of the moving magnet and likewise has no appreciable effect on its permanent magnetization. The shield material is of such low

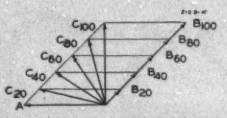

Figure 4. Vector diagrams of fluxes at intervals of 20 per cent of full-scale current

(*A*) Control magnet flux
(*B*) Coil fluxes for currents indicated by subscripts
(*C*) Resultant fluxes

coercive force as to be practically incapable of acting as a permanent magnet. It is evident that under the conditions of operation no appreciable shift in the permanent magnetization of any of the parts is possible, and hence the instrument will have negligible hysteresis errors.

The current-conducting coil is placed in the circuit to produce a magnetic flux at an angle of 135 degrees from the flux of the control magnets. This coil is shown schematically in Figure 3.

The vectorial relationship of the control-magnet flux and coil flux is shown in Figure 4. Vector *B* represents the coil flux. This flux is proportional to the current flowing in the coil and is shown in various magnitudes with the subscript indicating the percentage of maximum current. These *B* subscript vectors add to vector *A* to produce vector *C* with subscripts as shown.

The polarized rotor will turn to a position parallel to vector *C* subscript. It should be noted that, although vector *C* may vary in magnitude as well as direction, only the directional changes can cause the rotor to turn.

In Figure 5 the angular position of vector *C* is plotted with the per cent coil current. Since this angular position is the same as the pointer position, the plot shows the scale distribution obtained from an instrument of this type. The maximum deviation from uniformity, as shown by the straight dotted line, is five degrees.

It is at once apparent, if changes in magnitude of vector *B* produce directional changes in vector *C*, that like changes in magnitude of vector *A* will also produce the same effect. Use of this fact is made in calibrating the instrument to a predetermined full-scale current value. This is accomplished, as previously mentioned, by sliding the adjusting magnet of Figure 2 in or out of the metal shield cup, and thus changing the amount of control-magnet flux as represented by the magnitude of vector *A*.

Figure 6 is a cut-away view of one of the instrument elements.[5]

The element shown has polished steel pivots moving in brass bearings. This type of bearing can be used where torque-to-weight ratios are sufficiently high.

The copper damping cylinder is used to bring the rotor to rest rapidly, by means of eddy currents induced by the rotor.

The field coil is wound at an angle across the molded coil form and not parallel to the rotor axis, as shown schematically in Figure 4. This was done for mechanical reasons and in no way changes the previously discussed considerations, since the field of the coil has a component in the plane of vector *B*.

Zero adjustment is accomplished by rotating the whole element assembly by means of an arm welded to the bottom of the shielding cup.

The magnetic shielding is completed by means of a mumetal washer on the top of the molded coil form.

The element as measured on the outside of the shielding cup is approximately three-fourths inch in diameter, and one-half inch long.

Conclusions

In production quantities the element has been applied to only one device. This is a dual-range storage-battery testing type of voltmeter shown in Figure 7. Here it was possible to use brass bearings. In all applications seen by the authors of moving-coil permanent-magnet instruments to similar devices, jewelled bearings are used.

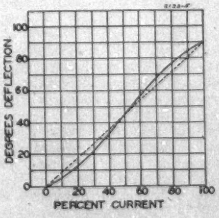

Figure 5. Scale-distribution curve for moving-magnet instrument

Table I shows the physical constants of these voltmeters.

The elements are adjusted to fit predetermined scales to an accuracy of ±2 per cent of full-scale reading.

No hysteresis error (measured by taking calibration at the same point with descending and ascending currents) can be detected.

The instrument, when placed in a stray field of ten gausses in such a manner as to produce maximum errors, changes read-

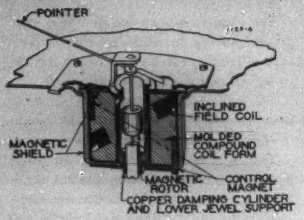

Figure 6. Cross section of moving-magnet instrument

ings approximately one-half of one per cent of full-scale reading.

The temperature errors of these indicators show some peculiar characteristics because of the high magnetic temperature coefficient of the silver alloy control magnets. With 10 per cent copper in the circuit, the element shows an error of −4 per cent at −40 degrees centigrade and +2 per cent at +50 degrees centigrade. With 35 per cent copper the error at −40 degrees centigrade is +1 per cent, and at +50 degrees centigrade approximately 0 per cent. The per cent errors are deviations from readings taken at 20 degrees centigrade. This makes it possible to build a voltmeter of low temperature coefficient with a high ratio of coil to series resistor resistance. Temperature compensation of ammeters may be obtained

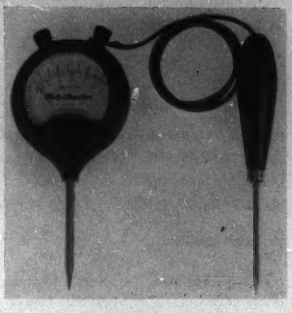

Figure 7. Battery-testing voltmeter with moving-magnet element

by a shunt resistor having a low temperature coefficient of resistance.

The element as used in these battery testers withstood considerable abuse. Several were tested by dropping 30 inches onto hard wood and concrete floors. No changes were noted except in one case where the adjusting magnet came loose.

The authors feel the element has inherently lower cost features and will withstand more abuse than the conventional moving-coil permanent-magnet element. By extending the design to the use of jewels, the sensitivity can be increased. Although it cannot reach the higher sensitivities of moving-coil permanent-magnet design, this moving-magnet element can be produced in sensitivities high enough to fit many applications now using the latter design.

Table I

1. Scale angle	90 degrees
2. Scale radius	$1^{13}/_{32}$ inches
3. Scale length	$2^{3}/_{16}$ inches
4. Full-scale torque (T)*	0.35 millimeter-gram
5. Weight (W)	0.205 gram
6. Ratio T^*/W	1.7
7. Ratio T^*/W 1.5	3.9
8. Response	1.5 seconds
9. Rating	3/10 volts
10. Ohms per volt	20
11. Coil resistance	20 ohms
12. Coil watts (full-scale)	0.05
13. Coil ampere-turns (full-scale)	14

*The full-scale torque shown (T) should be multiplied by approximately 3/2 to be comparable to the conventional 90-degree torque of moving-coil instruments. This is for the reason that the torque-versus-angular-displacement curve of the moving-magnet instrument is roughly sinusoidal and not linear as in the case of the moving-coil instrument. The 3/2 figure comes from extending the slope of the torque-displacement curve from near the origin, to the 90-degree point. This is logical, since it is the increment of torque-near-zero displacement which determines the inherent friction "stickiness" of the indicator.

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Sleet Problems on Electrified Railroads

H. F. BROWN
MEMBER AIEE

Synopsis: Sleet storms, or more properly ice storms, have always presented serious difficulties to the operators of overhead electric conductors of all classes. For more than 25 years some electric-power companies have been using the circulation of electric current to heat the conductors, either to melt off the ice or to prevent it from forming. The technique of such procedure is well-known and will not be dealt with in this paper, other than to present fundamental theoretical data.

Electrified railroads operating with overhead contact systems have similar ice storm problems, and, in addition, a number of special problems caused by such ice. These problems are outlined in this paper, and some means which have been used or proposed for their solution are described. Operating experience with one special application to a case of severe exposure to ice storms and high wind velocities is cited. Some of these special railroad problems have not yet been satisfactorily solved.

General Problems

THE accumulation of ice caused by freezing rain, also known as sleet or glaze, on overhead electric conductors has always presented problems to be dealt with by operating engineers as well as by the designing engineers of such systems. Ice loads must be taken into account in calculating the strength of the conductors and their supporting structures, and the National Electrical Safety Code[1] has set forth the different values of radial thickness of ice which may be expected to occur in the various parts of the United States. However, even the most liberal provisions for ice loads are exceeded during the occasional unusually severe ice storms, and the conductors and even their supporting structures may then fail.

Ice storms are frequently followed by a drop in temperature accompanied by high-velocity winds, and both the designers and the operators are then faced with additional problems, for to the static ice loads may be added dynamic forces caused by swaying loads, and under certain critical wind velocities ice-covered conductors will whip up and down and "dance" violently even to the extent of destroying themselves or their attachments to their supporting structures.

To mitigate all these effects, which cannot always be provided for economically in the design, ice melting by heating the conductors with electric current has been resorted to by many power companies. This is done by loading the lines to capacity where possible, by load concentration or exchange with connected supply lines, or by the circulation of sufficient electric current at a voltage lower than normal; and routine procedures have been established during such storms to remove or to prevent the forming of ice on the conductors by these means.

The theory of such current requirements and the various operating techniques used have been reported in the technical press and in papers before operator associations from time to time during the past few years, some of which are listed herein for reference.

Special Railroad Problems

Electrified railroads having overhead contact systems and associated power feeders must deal not only with the same general problems of this nature that electric-power-transmitting companies have, but in addition they have a number of associated problems peculiar to themselves to contend with during ice storms. Some of these are:

1. On the contact wire, the ice accumulation, in itself a poor conductor, interferes with the current collection if it becomes too thick and causes severe arcing, which can seriously damage the contact conductor by burning and pitting; and can even cause flashovers where clearances to grounded structures are limited or reduced. Frequently the collector shoe can be burned in two by such arcing before many miles have been traveled. Contact wire wear is increased by the roughened collector shoe, and the fine polish acquired by months of lubrication or otherwise, may be destroyed.

2. The static ice load on the catenary contact system may become great enough to distort the vertical alignment by greatly increasing the sag at the center of the span, causing the collector shoe to skip and arc at the suspension points, since the pantograph is usually sluggish in its action under such conditions. Where heavy ice accumulations are known to be possible, the designer should weigh this factor in the selection of span length, especially if high-speed operation is involved, since this distortion will increase directly with the square of the span length for the same weight of ice. With inclined catenary construction, the increase in static load may distort the horizontal alignment enough to dewire the collector shoe on long spans on curves of long radius. Here again the remedy lies with the designer by using shorter spans or applying adequate horizontal bracing.

3. The additional wind load on the ice-covered contact system may result in further alignment distortion caused by horizontal sway, or in vertical "dancing," which, even if not severe enough to damage the overhead system, is in itself detrimental to continuous current collection and to high-speed operation and continuous tractive effort. Violent dancing may under extremely severe conditions wreck the line. Adequate bracing to take care of horizontal sway may have no beneficial effect on and may even augment this vertical dancing under critical conditions.

4. The ice accumulation on the pantographs and overhead collector shoes may add so much extra weight to these parts as to completely nullify the normal spring tension which holds the shoe against the contact wire. Then the pantograph will drop away from the wire or will not rise again after having been depressed, where the contact wire is lower than normal, as under a highway bridge or other low overhead structure. A means of augmenting the normal spring pressure, by added air pressure or otherwise, is one means of overcoming this difficulty; but it must be remembered that the pantograph pressure cannot be made too great without affecting the contact system.

5. Electric melting of ice on the overhead contact system may require larger currents than are available, since such systems are, in general, designed with more conductivity and for heavier currents than in the average power-transmission lines, which are usually of much higher voltage. Further, even when large currents can be applied, they may concentrate in the messenger or in some associated wire other than the contact wire, as some contact systems may be designed to have most of the conductivity in some member other than the wearing wire. In general, it is desirable to have the heating take place in all the members of the contact system, to overcome the difficulties outlined in paragraph 2 above as well as those in paragraph 1.

6. Unlike ice-melting schemes used on power-transmission lines, any electric ice-melting scheme used on an overhead contact system must allow of being superimposed on the contact system circuit while it is normally energized with traction power for train operation; that is, the heating current must be of such characteristics that it will not interfere with the electric operation of trains supplied with power from that same wire or circuit. For example, it is obvious that direct current cannot safely be superimposed on a-c circuits without the danger of saturating the a-c equipment and rendering it inoperative or possibly damaging it by overheating. If it becomes necessary to remove the traction power to apply a heating current of different voltage or characteristic—as may be done often on power transmission lines—there would be no advantage of such a method over the suspension of elec-

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tric operation entirely and the substitution of steam or other form of motive power for the duration of the storm—an extremely inefficient, if not impossible procedure on a system having dense traffic.

Within the past two or three years, several unusually severe ice storms in the northeastern part of the United States have caused all of the electrified railroads in this section which operate under an overhead contact system to give more attention to these special problems, with the objective of preventing the ice from forming on the contact wire or collector parts, or of removing the accumulated ice before the deposit becomes unduly troublesome.

This paper will discuss some of the various solutions which have been found or suggested for these special railroad problems, rather than those which have generally been applied to power transmission lines. Some of the fundamental data are applicable to these special problems, as well as the general problems, and hence are included herein for reference.

Electric Heating of Overhead Conductors

Pender's Handbook gives the following formula for the value of the current, I, required to heat a conductor:

$$I = K\sqrt{\frac{Td^3}{r}}$$

where

T is the temperature rise in degrees centigrade
d is the diameter of the conductor in inches
r is the resistance of the conductor in ohms per mil-foot at final temperature
K is a constant depending upon surface condition of wire; whose value is (approximately) 800 in still air and 1,000 in open air for solid wire; and 1,200 in open air for stranded conductors

F. R. Longley of Western Massachusetts Companies in an excellent paper on this subject presented at a symposium of System Operators of New England at Montpelier, Vt., June 25, 1937, has developed the curves shown in Figures 1 and 2, which show the amperes required to heat conductors in still air, and the cooling effects of cross winds on the temperature rise, respectively. His formula was developed from data reported by Schurig and Frick.[2] It is to be especially noted that low wind velocities cause a marked reduction in temperature rise, while wind velocities in excess of 15 or 20 miles per hour do not produce much additional reduction. It is obvious that all these formulas are applicable to railway feeders and to the various wires of the catenary contact system.

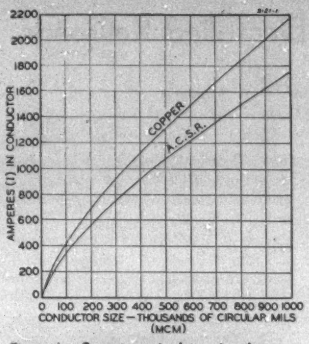

Figure 1. Current required to raise the temperature of a conductor from 0 to 150 degrees centigrade in still air (Longley)

This current is recommended for ice melting. Maximum temperature rise out of doors probably will not exceed 120 degrees centigrade, due to cooling effect of minimum crosswise wind velocity of one mile per hour. Conductors will not anneal below 175 degrees centigrade

For copper $I = 17.5\ (MCM)^{0.694}$

For steel-reinforced aluminum $I = 14.3\ (MCM)^{0.694}$

Mechanical Removal of Ice From Contact Wires

Most of the railroads which have been electrified in the northeastern part of the United States have rather frequent and dense traffic—in most cases one of the factors responsible for the electrification. Under such conditions, the usual ice storm presents no especial problem, as the ice or glaze is scraped off or shaken off from the contact wire before it has a chance to build up to a troublesome thickness, by the frequent passages of the pantographs. This is one method of ice removal which power-transmitting companies cannot use. On branch lines where traffic is light, or during the night or at other times when traffic is less frequent, if the ice formation and accumulation is mainly because of infrequent train operation, a special car or locomotive (electric) may be assigned to operate frequently to and fro over such lines to keep these lines as clear by this means as those having denser traffic.

A method of prevention of the formation of ice coatings which has been tried out on some of the 600-volt d-c urban lines, especially where trolley coaches with sliding collectors are used, and where even a light ice covering presents a very real problem to continuity of service, has been to coat the contact wire with a waxy or greasy substance which will not become wet enough by light rain to allow the formation of a continuous film but will cause the water to collect in drops. This may be partially successful in light ice storms of short duration, but since the drops which adhere and freeze have the same surface tension as the rain drops, they finally unite to form a continuous coating. Very possibly the waxy coating causes the ice coating to be less adherent, but when the temperature drops, it remains on the wire until scraped off by the collector shoe. This measure obviously is

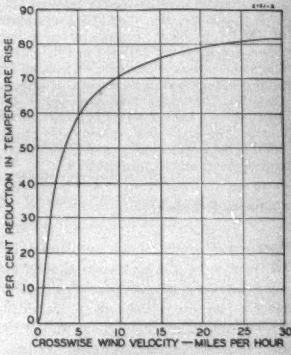

Figure 2. Cooling effect of crosswise wind on heated conductor (Longley)

ineffective for very severe storms and is not economically applicable to the contact systems of electrified railroads.

Special Cases and Their Treatment —an Example

Certain sections of railway line may be exposed to unusual conditions favorable to the frequent and very rapid formation and accumulation of ice and to very high winds. On such sections even frequent traffic is not in itself sufficient to keep the contact wires clear of ice, and some other method of ice removal must be employed if service is to be maintained.

An example of such a section, having unusually severe exposure to both heavy and rapid accumulations of ice and to very high wind velocities, is that part of the electrified system of the New Haven Railroad known as the New York Connecting Railroad which operates over the Hell Gate Bridge in New York City between the Bronx and Long Island. For a distance of nearly four miles this part of the

railroad is on a viaduct which is from 75 to 165 feet above the ground or river level and at a considerable distance from any shielding structures. Ice seems to form very rapidly under certain conditions in this section and at times when it is not troublesome elsewhere, and the wind velocities in winter, especially after such storms, assume unusually high values. Consequently, this part of the overhead line has been damaged by ice and wind to the extent of being rendered inoperative electrically on several occasions since its construction in 1917. In contrast to this unsatisfactory record, the remainder of the line from New York to New Haven has operated successfully through a number of severe ice storms since its completion in 1914. With the exception of one extremely severe ice storm in December 1915, when accumulations were two inches in radial thickness in many places, causing the breakage, chiefly at splices, of some number 3 American Wire Gauge copper-stranded conductors used in 300-foot spans for control circuits, this overhead system has withstood a number of severe ice and wind storms (including the hurricane of 1938) without serious damage.

Mechanical Methods Applied

A number of studies of and changes in the Hell Gate Bridge section have been made in an endeavor to overcome the difficulties with ice and wind. Very possibly a fundamental difficulty is that some of the spans used are too long for such severe exposure. In 1927 an extensive horizontal wind-bracing system was applied to the catenary system in this section. This bracing did not eliminate the vertical "dancing" of the catenary spans, and in 1933 some additional vertical stays were added to the horizontal bracing system. Obviously these measures did nothing to eliminate the ice problem. Ice on the contact wires was scraped off when possible by special "ice breaker" locomotives, operated as a routine procedure during each ice storm. The vertical dancing was still so great at times that even these locomotives were unable to keep their pantographs on the wire. The difficulties from ice and high winds continued on the feeders, which were on occasions during subsequent ice storms broken in two and torn from their supporting pin insulators in many places by the violent wind whipping. The ground wire suffered the same fate, and it is safe to say that there are but few spans in this entire section where some of these conductors have not been broken and spliced. The feeders are 4/0 American Wire Gauge hard drawn stranded copper, having a normal sag of five feet in a 300-foot span, and it is a rather awesome sight to see these heavy conductors whipping up and down in a storm for 10 or 15 minutes at a time, with a frequency of about 25 vibrations per minute and with maximum amplitudes of twice the sag at the center of the spans.

In 1937 a number of experimental changes was made to the feeders, including the installation of some experimental dampening devices similar to the Stockbridge dampeners, but of various weights and dimensions. Some experimental spring suspensions and spring dampening devices were included, and in a number of spans the feeders were removed from the pin insulators and attached to suspension insulators. None of the dampening devices proved of great value during the following winter, but the wind whipping seemed to be materially reduced on those spans where the suspension insulators had been substituted for the original pin insulators. These experiments led to the general substitution in 1941 of suspension insulators for pin insulators on all the feeders throughout this entire section, except on the very short spans in the 1,100-foot section across the main arch span of the Hell Gate Bridge, where pin insulators with a flexible mechanical clamping arrangement are used.

The ground wire also has been flexibly suspended, so that any structure vibration caused by the whipping of the catenary will not be communicated to this wire. Some additional lateral and cross bracing of the catenary contact system was also installed in 1941, and to date these changes have seemed to be effective, as no serious difficulty has been experienced this past winter, although the season has not been a severe one.

Electrical Methods Considered

During the summer of 1939 serious consideration was given to the possibility of melting sleet from the wires in this section by electric heating.

There are four tracks in this section, an eastbound and westbound track each for freight and for passenger service, not connected by crossovers except at some distance east of the section, so that this section is operated as two two-track railroads. There are four contact wires with catenary construction at 11,000 volts to rail, and four feeder circuits, also 11,000 volts to rail, but 22,000 volts to the contact circuits, thus making with the rails a three-wire system. All contact circuits and feeder circuits are sectionalized at switching stations at each end of the exposed section approximately four miles apart. All trolley contact circuits are connected to a "trolley" bus, and all feeder circuits are connected to a "feeder" bus at each station, with a 3,000-kva "balancer" transformer having center point of winding connected to rails, connected across these trolley and feeder busses at each station. The west switching station is unattended and is operated by supervisory control from the east switching station, which is located at a signal interlocking tower, thus making the east station the more desirable location for any additional switching or heating apparatus.

In order to electrically remove the ice after it had been once formed, it was assumed that the temperature of the wire would have to be raised about ten degrees Fahrenheit between the two switching stations. It was calculated that about 750 amperes would be required in the catenary system (consisting of a bronze messenger, copper auxiliary wire

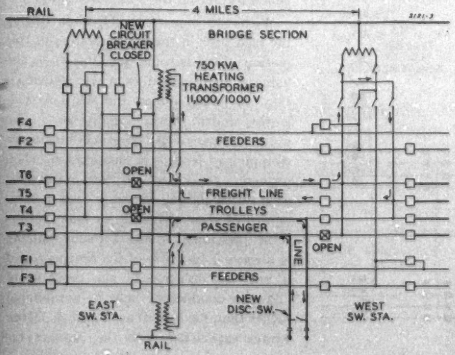

Figure 3. Scheme I proposed for heating contact wires on Hell Gate Bridge

and 4/0 bronze contact wire) to cause enough current (approximately 200 amperes) to flow in the contact wire to raise its temperature the required ten degrees Fahrenheit, since the greater part of the current would flow in the auxiliary wire and a smaller part in the messenger. The d-c resistance of this four-mile section of catenary is approximately 0.5 ohm, which gives a drop of 375 to 400 volts between stations. The a-c impedance is approximately ten per cent higher.

The problem, therefore, was to circulate in a loop circuit between sectionalizing points approximately 750 amperes at 900 to 1,000 volts a-c, or about 750 kva. A smaller amount of power and current would be required if a smaller rise in temperature would keep the lines clear when applied before and during the ice storm. The air temperature during an ice storm is always between 30 and 34 degrees Fahrenheit and if the temperature of the wire could be maintained at, say, 37 degrees Fahrenheit ice could not form on it.

Two schemes, both believed to be practical, were proposed and developed. Scheme I, shown diagrammatically in Figure 3, contemplated using two special 11,000/1,000-volt 25-cycle transformers, having their 11,000-volt winding connected to the trolley bus through a circuit breaker at the east switching station. The 1,000-volt winding would be provided with five or six taps at 50-volt intervals, with tap-changing facilities to suit temperature conditions, and would be insulated to withstand the normal contact-wire voltage plus the usual surges experienced on the system. This winding of each transformer would be connected through disconnecting switches, one to the two freight-line contact wires, and the other to the two passenger-line contact wires. These switches would be closed prior to the advent of the ice storm, and if the storm developed, the circuit breaker would be closed by the tower operator, and two of the trolley circuit breakers would be opened at the east switching station to disconnect one side of each loop circuit from the bus to prevent short-circuiting the low-voltage windings. The heat would then be on the bridge section without further switching operations, and train operation could be maintained and handled as required with no interference from the superimposed heating power. Two trains, both passenger or both freight, when passing near the easterly end of the section might temporarily bypass a small amount of this current, but it would be negligible because of the high impedance of the locomotive transformers to the 1,000-volt heating current.

The passenger line diverges from the freight line at the west switching station and continues for another mile, where it joins another system. If it were desirable to heat these circuits, a new disconnecting switch could be installed at the end of this section as shown in the diagram, closed during an ice storm, and one of the circuit breakers on this line could be opened at the west station to avoid short-circuiting this part of the line. This scheme could be expanded by additional switches, or by separate transformers to heat the feeders in the same manner, although this was not felt to be so urgent at that time.

This scheme was believed to be practicable but was not applied—partly because of the necessity for investing in the special transformers, when at that time it was unknown just how efficacious the heating current would be on the trolley circuits, but mainly because another method, involving no investment or additional equipment of any kind, was immediately available for experimental work by the simple expedient of power exchange between supply points on either ends of this section.

This second scheme is shown in Figure 4 and involved the exchange of traction power from the supply station several miles east of this section, over one circuit at a time in the section, either trolley or feeder, to the supply point several miles west of the section. At both supply points power is purchased from the same power company, but under separate contracts, because the supply at the western end is to a different railroad company over whose lines the New Haven circuits extend. This supply is through a 7,200-kva motor-generator set, designed for power flow in either direction, which was ideal for the purpose in mind.

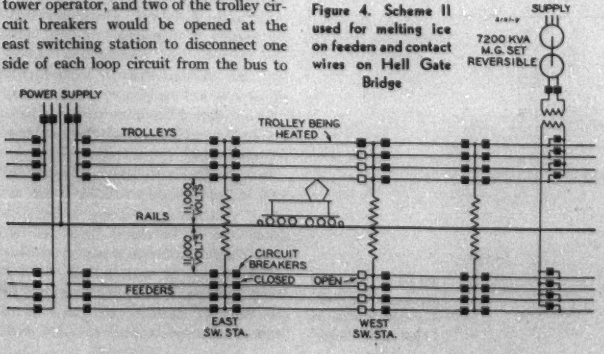

Figure 4. Scheme II used for melting ice on feeders and contact wires on Hell Gate Bridge

It will be seen that scheme II involved the use of a single trolley-rail circuit for contact-wire heating, or a feeder-rail circuit for feeder heating, in the bridge section, which necessitated some experimental tests to satisfy the local communication interests that no inductive disturbances serious enough to cause any interference with their plant could be detected; and after some further tests to develop operating technique, this scheme was adopted as a regular operating procedure to be used throughout the duration of ice storms and has been in successful operation for three seasons. This scheme has been more fully described elsewhere.[4] One of the features of the power exchange is that it is done on a half-hour basis; that is, power is taken from one supply for one half-hour and delivered (less losses) to the other supply, after which interval the power flow is reversed for the next half-hour. This is because both contracts have the maximum demand on an hourly basis, and in this way neither contract demand can be exceeded by the power exchanged. A typical power curve illustrating this feature is shown in Figure 5.

With scheme II ice already formed can be melted from the feeders in from six to ten minutes and from the catenary in about twice this time, depending upon the temperature and wind conditions and the amount of power exchanged, which is limited by the capacity of the motor-generator set at the western supply.

With the improvements made during the past year in the feeder system in this section, there is some question as to the value of ice removal from the feeders, if they no longer dance and whip so violently under storm conditions. The writer has personally observed dancing or whipping of feeders in this section, when formerly supported on pin insulators, with no ice coating whatever, and at temperatures above freezing, so that there is some question as to whether such dancing is always a function of ice coating; and if not, the solution of the problem of "dancing conductors" may be mechanical rather than (or as well as) thermal. More winter experience with the changes re-

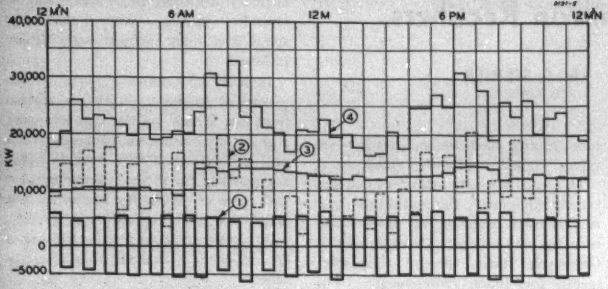

Figure 5. Power-load curve for March 4, 1940

①—Ice-melting power exchanged with west supply

②—Total purchased power, excluding ice-melting power from west supply

③—Power produced at railroad-owned plant

④—Total railroad-system load, excluding ice-melting power exchanged

cently made must be had before it can be definitely stated that this problem has been solved.

Further Considerations

It will be noted that scheme II involves the continuity of service of all equipment involved in the power exchange; and if the equipment at the western supply point, which is not in duplicate, should be out of service for any reason during an ice storm, the scheme could not be used. This actually did happen during a very severe ice storm early in 1941, and, consequently, later in the year the proposal was made that a scheme similar to scheme I, outlined above, be installed until it was learned that it would be impossible to obtain the necessary transformers because of the war.

A third scheme therefore, to be used only as an alternate to scheme II, has been devised and is now being installed. This scheme consists of taking one trolley or feeder circuit at a time in this section and switching the westerly end through a water rheostat, adjusted to allow the passage to ground (rail) of approximately 800 amperes of traction power supplied from the east end. Most of this power is necessarily lost, being dissipated through heat in the water rheostat; possibly five per cent is used in heating the wire. This scheme requires a number of disconnecting switches at the west switching station, a large tank of water with a continuous supply, and the necessary drains, to dissipate the large amount of waste heat, also sending operators to this unattended station and housing them there for the duration of the storm. It is expected that this installation will be ready for the next winter season.

It is obvious that a similar method might be applied to any electrified railroad, a-c or d-c, if the economics of the situation warranted.

Ice or Sleet on Pantographs and Collectors

The problem of ice accumulations on pantographs and collector shoes has been approached from a number of different angles. The usual and time-honored practice is to work the pantograph up and down by means of its own operating mechanism at frequent intervals during ice storms to jar off the ice accumulations mechanically. Obviously this means cannot be employed on long high-speed runs. It is also customary practice to use higher spring pressure during the winter, partly for the purpose of compensating for the expected additional ice load, and partly to exert more pressure on the wire for knocking off the ice on it. Mention has already been made of the possibility of augmenting the normal pressure at will by auxiliary air pressure, to overcome excessive added weight.

Another proposal is to provide steam jets on top of the locomotive to blow steam from the train-heating boiler at will over the pantograph frame in the lowered position. Obviously this scheme is not applicable to pantographs on motor-cars, since they carry no steam-heating equipment. Another method which has been proposed for a-c electrified railroads is to have the pantograph frame split electrically at the base and all up through the frame, connected electrically only at the top by the contact shoe, and to circulate through this split frame a low-voltage current applied across the base from a separate special transformer, sufficient in value to raise the temperature of the entire frame and shoe. This current would be applied when necessary by the engineman. The traction power circuit would be connected to one side only of the base. Obviously, this scheme is not applicable to pantographs on equipment operated by direct current, at least without additional conversion apparatus.

Coating the frame and shoe with a waxy or greasy substance has been tried and is thought by some to be helpful in delaying the formation of adherent ice on pantographs. This measure has already been commented on in connection with the mechanical removal of ice from contact wires, and those comments apply here. It is possible that accumulated ice can be more easily jarred off the pantograph by working it up and down, when such coatings are applied, but again, this is a function of the temperature as well as the thickness of the accumulation.

Summary

Ice storms cause special problems on electrified railroads which power transmission systems do not have, most of them involving the current collection.

Ice accumulations may be removed from overhead contact systems by mechanical or electrical means.

Electrical heating of the contact system has been used satisfactorily on one a-c electrified railroad for a special case, and three methods of doing this have been devised, some of which may be applicable to other railroads.

The problems caused by high winds on ice-covered conductors are shared with other power-transmission systems and are serious ones. Changes to existing plant may help, but the possibilities of these difficulties should not be overlooked in the original design.

Ice accumulations on pantographs present special problems which are recognized and are being solved in various ways.

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Sealed-Tube Ignitron Rectifiers

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IN the past decade the advantages of the rectifier, when compared to other forms of conversion equipment, have led to the development of multianode steel tank and glass-bulb rectifiers. The desirable structural features and operating characteristics, however, have not been fully realized when pump-evacuated tanks and fragile glass-bulb rectifiers have been applied to small conversion units of low-voltage rating. Development of a means of starting or igniting[1] a cathode spot, each positive half cycle, on a pool of mercury has stimulated the design of a practicable half-wave or single-anode rectifier. The low density of ionization during the inverse cycle so reduced the shielding necessary to prevent arcback and, in consequence, the arc losses, that these rectifiers could be efficiently applied in the lower-voltage (250 volts d-c) fields.

Sealed, permanently evacuated steel ignitron tubes have been used in the control[2] of resistance welding currents for the past ten years; and in such service these electronic devices have given a degree of control, speed, and reliability not previously matched by mechanical means. Sealed, permanently evacuated steel ignitron tubes for rectifiers ranging in capacity from 75 to 400 kw (at 250 to 600 volts d-c), have been developed and placed in service, and it is the purpose of this paper to describe the design, characteristics, and performance of these rectifiers.

The Field for the Permanently Evacuated Tube-Type Rectifier

The field of application of the mercury-arc rectifier is considerably enlarged by the use of permanently evacuated tubes in circuits which have output characteristics similar to those of a d-c generator with nominal field control. Despite almost universal use of alternating current for generation and distribution, direct current still provides the most suitable source of power where adjustable speed or controlled torque characteristics are desired. D-c motors for machine tools, business machines, magnetic chucks, and separators, grinding machines, and elevators are typical examples of these d-c loads.

In comparison with other forms of converting equipment, the sealed-tube ignitron rectifier offers several distinct features for such service. The equipment is completely static, thereby eliminating special foundation requirements. The rectifier is quiet in operation which permits installation in locations where any appreciable noise would be objectionable. The over-all efficiency is high and practically constant over the entire load range. The no-load losses are small when compared with rotating equipment of like capacity. Rectifier equipments are factory-assembled, thereby minimizing installation time and expense.

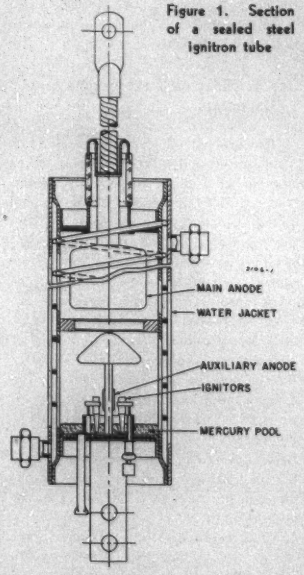

Figure 1. Section of a sealed steel ignitron tube

Tube Design and Operation Characteristics

Two sizes of ignitron tubes have been developed. The general tube design and construction are shown in Figure 1. The tube elements consist of a main anode, mercury-pool cathode, two ignitors, an auxiliary or holding anode spray, and deionization shields. Water jacket, flow spiral, and inner cylinder are of stainless steel.

Ignition[3] of a cathode spot is accomplished by passing an impulse of current from the ignitor to the mercury pool. Passage of current from the ignitor to the pool generates sufficient heat to break momentarily the contact of the mercury with some crystal in the ignitor. If the magnitude of the current, its duration, and the voltage gradient along the ignitor are sufficient, a cathode spot is established.

Figure 2 shows the variation in ignition voltage, current, and time for a typical ignitor, when supplied from the voltage of the main anode. When the ignitor is started at the beginning of the applied voltage wave, the current rise is slow, and the time required to reach the critical ignition value is long. When the applied voltage is high, as near the middle of the wave, the critical ignition current is quickly reached and the time correspondingly short.

Arc-drop voltages are given in Figure 3 in terms of anode current and outlet water temperature. These data were determined from cathode-ray-oscillograph measurements, while the tubes were supplying an inductive load of sufficient magnitude to insure essentially flat-topped current waves. Arc losses represent a design compromise between the minimum obtainable with no baffling and those with the shielding required to produce satisfactory freedom from arcback.

Cathode spots on a free surface of mercury become unstable when the instantaneous current decreases below approximately three amperes. To provide stable operation in this current range, an auxiliary anode has been added to the tube elements. This anode is usually excited from a low-voltage source inphase, or slightly ahead of the period of main anode conduction.

The tubes are water-cooled. Water-flow rates, cooling area, and temperature are determined by the requirements of removing the arc losses while maintaining vapor[4] pressure control. The outlet water temperature varies inversely with the load as is shown in the performance data of Figure 4. Maximum water temperatures are determined by the point at which the vapor pressure reaches arcback conditions. Minimum water temperatures are determined by the ability of the tubes to conduct current without "surging." This phenomenon is the result of insufficient vapor pressure to provide ions for the load-current demand. Momentarily con-

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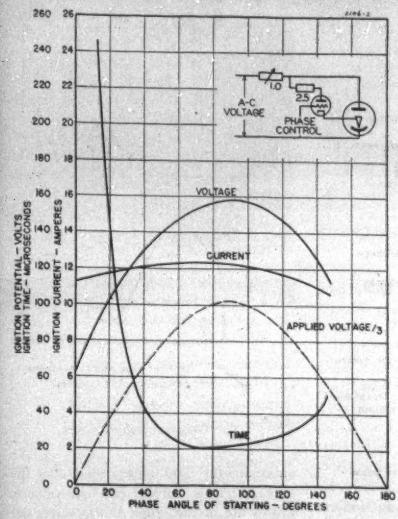


Figure 2. Ignitor characteristics

RECTIFIER KW RATING	IGNITRON TUBE NUMBER	IGNITRON TUBE AMPERE RATING	RECTIFIER POWER CIRCUIT
75	3	150	
100	4	150	
200	4	300	
300	6	300	
400	8	300	

Figure 5. Table showing typical power circuits and rectifying elements for 250-volt operation

duction ceases, and the rapid current changes in transformer and lead inductance generate high voltages. Surging is usually limited to the first few cycles of conduction and for the particular designs does not occur at full-load currents with water temperatures as low as ten degrees centigrade. At less than full load the temperature may be lower. Optimum operating temperatures are in the range of 30 to 50 degrees centigrade, since under these conditions the arc losses are nearly a minimum, and there is more reserve vapor pressure control to take care of current demands.

Ignitron tubes in common with most vacuum-tube devices have elements of relatively small mass. The time for averaging the heating effect of sustained current demands is therefore a matter of minutes rather than hours as found in more massive machinery. This time is adequate for clearing feeder fuses, starting motors and for the usual types of overloads that are encountered in service.

Rectifier Design and Performance

Power Circuits

The choice of rectifier power circuits permits the grouping of different numbers of tubes to obtain various rectifier capacities. Figure 5 shows some of the more common of these circuits, together with the number of rectifying elements required, and the nominal ratings which are obtained in 250-volt service. These nominal ratings are made on the basis of the continuous duty. The usual overload factors are 125 per cent for two hours and 200 per cent for one minute. For most applications the circuits in which several tubes conduct simultaneously are preferable. In such circuits the total load is divided. Arc losses are therefore a minimum, since the instantaneous tube currents are low, and current capacity is a maximum. In certain cases, however, ease of control makes circuits preferable in which each tube carries the full load current. Rectifiers[6] which supply field currents for synchronous machines are in this category. To provide rapid response for both increasing and decreasing line voltage, the rectifier must be capable of inversion as well as of rectification, and the control is simplified when circuits of the three-phase, quarter-phase, or six-phase type are used.

Two-wire service is readily obtained from the usual rectifier circuits. Three-wire service may be obtained in two ways. A balancer set capable of carrying unbalanced currents of the order of 25 per cent of the set rating is usually sufficient to provide the required neutral. Three-wire systems may also be obtained electronically through the use of a three-phase, double-way[6] circuit shown in Figure 6. A practicable installation may consist of two-wire circuits to carry the main part of the load and sufficient three-wire circuits to carry the unbalanced load.

Ignitor Excitation

Anode excitation[7] is the most direct method of establishing a cathode spot. In this case a portion of the load current is diverted through the ignitor by means of a

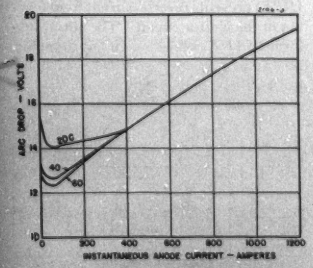


Figure 3. Arc-drop characteristics for cooling water temperatures of 20–60 degrees centigrade

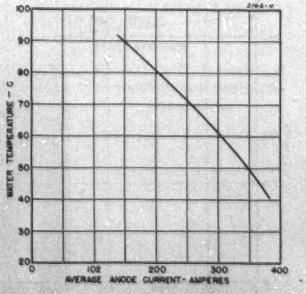


Figure 4. Arcback temperatures for operation at 250 volts in a three-phase single-way circuit

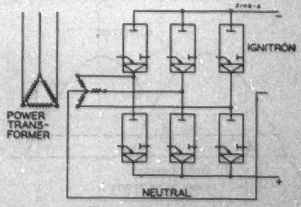
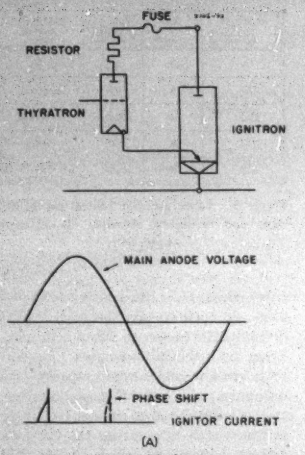
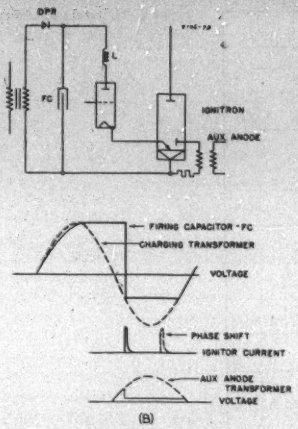


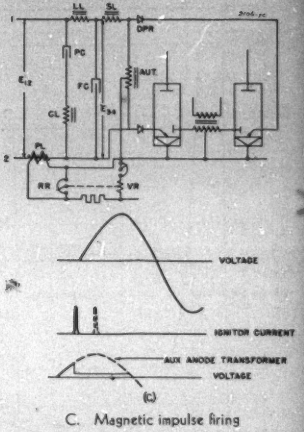
Figure 6. Three-phase double-way rectifier for three-wire service



A. Anode firing



B. Capacitor firing



C. Magnetic impulse firing

Figure 7. Ignitor excitation systems

suitable thyratron control tube. Establishment of the main arc effectively shorts the excitation system and thereby limits the average ignitor current to practicable values. This system is shown schematically in Figure 7A. The anode firing excitation system has two limitations. When the rectifier is feeding a counter electromotive-force load, and the current is low, the anode currents tend to become discontinuous. The voltage which can be applied to the ignitor becomes the difference between the instantaneous transformer voltage and that of the counter electromotive-force load. This voltage difference is so low that either a relatively long period is required for the ignitor current to reach the critical ignition value or the counter electromotive-force voltage decreases sufficiently to provide the required ignition current. Momentarily, therefore, the rectifier ceases to deliver its normal output voltage. This effect can be corrected by providing sufficient series inductance in the d-c load to assure that the current is continuous. Even though the load current is continuous, it may drop below the critical ignition value. In effect the ignitor resistance is suddenly placed in the circuit. The resulting reduction in output voltage can produce a very annoying light flicker when lamps are part of the connected load.

One form of separate excitation is shown in Figure 7B. In this case a capacitor (*FC*) is charged through dry-plate rectifier (*DPR*) and discharged at the proper instant through a thyratron tube. Phase control is obtained in the usual manner through the thyratron grid. An inductance in the discharge circuit establishes the desired rate of rise in the ignitor current. The circuits are so designed that a relatively high peak current, approximately 25 to 30 amperes, is available prior to ignition. This current value is in excess of the usual requirements, but, since the available energy is fixed, a design factor must be included for any possible contingency. The duration of the impulse is approximately 500 microseconds and the average ignitor current one-half ampere. Losses are of the order of 100 watts per ignitor. The ignition current is of such short duration that the cathode spot is maintained for the remainder of the main-anode conducting period by an auxiliary anode. Average current in this circuit is of the order of two amperes and losses 50 watts.

The required peak excitation current may be obtained[8,9] magnetically as shown in Figure 7C. Operation of the circuit is as follows: The linear reactor (*LL*) has an iron core with an air gap and is designed to give a constant reactance up to rated voltage and frequency of the circuit. The saturating reactor (*SL*) is built with a closed high-permeability core and a winding which will draw a large magnetizing current at the saturating point. This peak of current occurs when the capacitor (*FC*) is charged to its maximum voltage. The capacitor discharges through the saturating reactor, giving an impulse of ignitor current. A dry-plate rectifier (*DPR*) prevents reverse current from flowing in the ignitor circuit. The autotransformer (*AUT*) allows one circuit to supply excitation power to two tubes, which are in 180-degree phase relation.

The phase position of the impulses

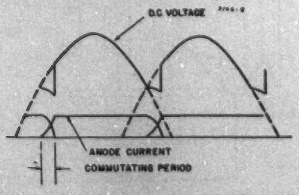


Figure 8. Diagram showing voltage loss due to commutation

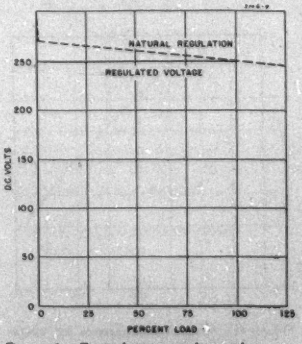


Figure 9. Typical output-voltage characteristics obtained by phase control

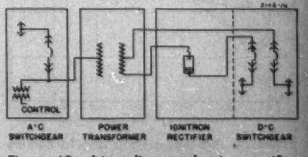


Figure 10. Line diagram showing rectifier component parts

Figure 11. Metal-enclosed ignitron rectifier with automatic d-c switchgear for general purpose use

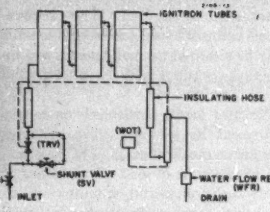


Figure 13. Water-cooling system of a 75-kw ignitron-tube rectifier

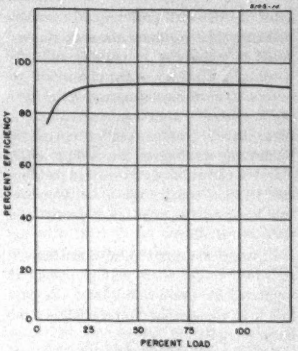


Figure 14. Over-all efficiency for a 250-volt 75-kw ignitron rectifier

which establish the cathode spot are controlled by shifting the supply voltage (E_{34}) to the excitation circuit. This is accomplished by means of the network, consisting of reactor (CL) and (PL), and capacitor (PC). The reactor (PL) is capable of gradual change in reactance over a 10 to 1 range by means of d-c saturation. The reactor (CL) and capacitor (FC) operate with a circulating current larger than that drawn by the excitation circuit and act as a power source for this circuit. The phase position of the voltage (E_{34}) can be adjusted by controlling the point of saturation in the phase-shifting reactor. In this manner a 40-volt-ampere d-c source may be used to vary the firing point of the ignitor over an angle of approximately 50 degrees.

Fault Protection

Fault protection must be provided for a-c and d-c short circuits and for tube arcback conditions.

A-c protection for the transformer circuits is taken care of most satisfactorily by means of circuit breakers. The interrupting capacity of such a breaker is determined by the system capacity from which power is obtained.

The d-c protective equipment should provide for the usual functions of overload and short circuit. Again breakers are usually preferable, at least for the main feeders.

In spite of almost complete freedom from arcback when circuit, tube, and load conditions are properly co-ordinated, provision must be made for the possibility of arcback. Anode fuses of proper characteristics and capacity have proved satisfactory for this service. Differential protection can be obtained by the co-ordination of the tube current-carrying capacity with the transformer current-limiting reactance. The proper relationship of these two factors permits the remaining tubes in the circuit to carry the transformer short-circuit current without arcing back, for the eight or ten cycles required for the fuse to open. Likewise d-c short circuits may be cleared with the rectifier remaining available for service.

Voltage Control and Regulation

Regulation in rectifier circuits is due primarily to the voltage lost during the commutation period. At this time two anodes are conducting simultaneously, and the output voltage is the average of the instantaneous voltages. These conditions are shown in Figure 8. The voltage loss[10] during the commutation period is

Voltage drop $= PFLI$

where

P = number of phases or anodes which commutate consecutively

F = system frequency

L = commutating inductance of one phase in henries

I = d-c current at the beginning of current transfer

The commutating reactance is that of any two phases whose anodes conduct in turn. It may be determined by shorting the transformer primary and applying excitation current to the secondary phases.

Rectifiers of this type usually have voltage regulation of six to seven per cent. This regulation is often greater than is desirable. To mitigate this effect, as well as compensate for variation in the voltage supply to the rectifier, the phase of the ignitor impulse is varied with respect to the positive half cycle of anode voltage to control the starting point of the anode current.

For magnetic excitation circuits, the simplest method of controlling the rectifier output voltage is to vary the d-c saturating current in accordance with the variation in the d-c output of the rectifier. In Figure 7C the voltage sensitive element (VR) of a torque-type regulator is connected across the d-c voltage to be regu-

Figure 12 (left). Installation of a portable ignitron rectifier for mining service

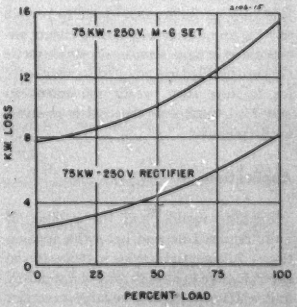


Figure 15 (right). Comparison of motor-generator and ignitron-rectifier losses

lated in series with a reactor and a variable resistor. The regulator rheostat element (*RR*) is connected in parallel with the saturating windings of the phase shift reactors. The voltage drop across the rheostatic element varies from a maximum to zero, thereby varying the current in the saturating winding of the reactor (*PL*). Parallel operation of one or more rectifiers can be obtained by use of an equalizer bus between the regulating elements of the various units.

Figure 9 shows a typical characteristic in which the rectifier voltage output is regulated from zero to full load. Beyond full load the output voltage follows the natural regulation.

Where extremely rapid response is desired, such as in the case of an electronic exciter operating to control the output voltage of a synchronous condenser, an electronic regulator[4] may be used.

Equipment Design

In general, the equipment design allows complete factory assembly of the units. The tubes, excitation, and control form one unit; the transformer another; and the required switchgear a third. A typical rectifier equipment is shown on the line diagram of Figure 10 and consists of the following components:

(*a*). Metal-enclosed manually or automatically operated a-c switchgear.

(*b*). Main, interphase, and control power transformers which are oil- or Pyranol-filled, natural or forced air-cooled, depending upon location and service.

(*c*). Metal-enclosed water-cooled ignitron mercury-arc rectifier with manually or automatically operated d-c switchgear.

Figure 11 shows a rectifier installation that is suitable for general purpose use such as lighting, power, or elevator loads.

Mine-service rectifiers require special designs in that the available head room is limited. Figure 12 shows a typical unit in which the rectifier, the transformer, and the switchgear form an articulated train. The cars are sufficiently short to permit moving around the usual track curves encountered in mine service. Portable rectifiers are particularly adapted to mine service, because they permit movement to new load centers as the coal is progressively removed.

Application

Rectifier ratings and the number of units required depend upon the application. In essential service it is considered good practice to have in reserve a stand-by unit which will permit the largest rectifier in service to be removed. Where requirements are less severe, and where the units may be removed for maintenance and inspection, rectifiers may be used to full capacity.

Elevator loads, particularly in hotels, apartment houses, and office buildings provide an excellent example of the essential service type of load. For reasons of safety such transportation must continue in operation. A satisfactory solution of the problem is to provide two complete and independent rectifiers with automatic change-over in case of d-c voltage failure. Simple switching provides preselection of the normally operating and reserve rectifiers, and the order may, of course, be periodically changed to equalize the use of the two units.

Tap water is usually used for removing the rectifier-arc losses. Full-load arc losses in 200-kw 250-volt rectifiers are approximately six per cent. Hence the transfer of

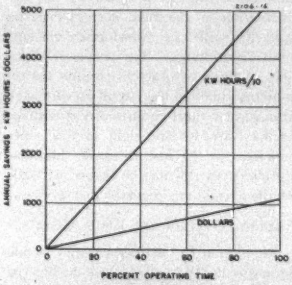


Figure 16. Annual savings for a 75-kw 250-volt rectifier

this loss into the water rather than into the air is desirable, particularly in locations having limited ventilation facilities. The cooling water is not contaminated in passing through the tube jackets, and may be used in plant processes. Figure 13 shows the usual arrangement in which water is supplied to the rectifier at line pressure and passes through regulating valves to the tube jackets. Valve *SV* is a shunt valve used to adjust minimum flow. Valve *TRV* is controlled thermostatically and regulates the water flow in response to load. Thermostat (*WOT*) protects against water over temperature while the water flow relay (*WFR*) will remove the rectifier from operation on loss of cooling water flow. The flow relay utilized depends for its operation upon a physical displacement requiring both hydraulic pressure and water flow.

In general, most waters which are suitable for industrial or public use are satisfactory for cooling requirements. Waters which readily deposit lime or silt are to be avoided. The stainless-steel jackets are resistant to most corrosive elements, and the usual temperature of operation is not conducive to lime deposits. Stainless steel, however, is subject to slight corrosion by waters containing chlorides. Generally waters containing below 20 parts per million are satisfactory. Most public water supplies do not contain more than 8 to 15 parts per million.

Where local water conditions are unsatisfactory for direct use, heat exchangers may be employed. For mine service, air-to-water heat exchangers have been found to be the more practicable. Mine waters, in general, are very corrosive and very dirty. Air temperatures, on the other hand, are relatively constant and sufficiently low to make air-to-water heat exchangers attractive.

Maintenance

Rectifier maintenance outside of the usual inspection which should be given any electrical apparatus is primarily a matter of tube renewals. The number and frequency of such renewals depend upon the ultimate tube life. This ultimate life logically seems to depend upon the ignitor or loss of tube vacuum. To provide for the former, sealed tubes have two ignitors, one of which is held in reserve. Actually, examination of ignitors which have operated for two to three years shows that no appreciable erosion has taken place. Experience over a four-year period indicates there is no impairment in the tube vacuum.

A direct approach to the problem of maintenance is to evaluate the annual savings in power cost resulting from the higher efficiency and lower no-load losses of rectifiers. Figure 14 shows the over-all rectifier efficiency, and Figure 15 the kilowatt loss of a typical 75-kw motor–generator set and an equivalent ignitron rectifier at various loads up to full rating. Between 20 and 80 per cent of rated load, the difference in losses varies from 5.5 to 6.8 kw. Since the usual load characteristics are such that the load on either a motor–generator set or a rectifier will rarely lie outside of this range, the annual savings in kilowatt hours obtained by using a rectifier can be approximated very closely by multiplying the number of hours in service by 6.1. The gross saving depends upon the cost of electrical energy. Although power costs vary considerably, rates of one to three cents per kilowatt hour are representative. Figure 16 shows the annual saving on the basis of a power cost of two cents per kilowatt hour in

Practical Design of Counterpoise for Transmission-Line Lightning Protection

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I. Introduction

EXPERIENCE has shown that preventive lightning protection, involving the installation of overhead ground wires and the co-ordination of tower-ground resistances with insulation level, can be quite effective in preventing flashovers due to lightning. Studies presented in an earlier paper[1] indicated that the efficiency of preventive protection can be made practically 100 per cent for high-voltage lines having insulator flashover levels of 1,600 kv and above. If the flashover level is reduced, the efficiency of protection becomes less.

Tower-ground resistance directly affects the protection efficiency obtained, and for satisfactory line performance resistance usually must be reduced below the values obtained with tower foundations alone. Buried counterpoise offers a practical means for accomplishing this, and, although many papers have been written on the theoretical aspects of the counterpoise, there is very little published on the problems encountered in actual installations.[2] This paper gives some methods that have been used in the installation of buried counterpoise at approximately 1,800 steel towers of the Pennsylvania Water and Power Company, as well as some of the results obtained.

When a counterpoise installation was contemplated, it was first necessary to determine the level of tower-footing resistances theoretically desirable. Next it was estimated how closely this objective could be approached and the amount of counterpoise conductor required. The data and methods presented are not sufficiently comprehensive to be applicable to all cases in all localities, but they may prove useful as a guide in making similar installations.

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II. Determination of the Optimum Tower-Footing Resistance

Experience has shown that in most cases flashovers will not occur at towers where the footing resistances are kept below the value indicated by the relation[3]

$$R = \frac{V}{I(1-CF)}$$

where

R = Tower-footing resistance
V = Impulse-flashover level of line insulation
I = Maximum natural tower lightning current
CF = Coupling factor between overhead ground wires and line conductors

This equation fixes the upper limit of footing resistance for any assumed value of tower current I, I usually being taken in excess of any tower currents that have ever been measured in the field.

Towers have suffered flashovers when the footing resistances and tower currents were appreciably less than the upper limit set by the above expression.[1,4] This has occurred more frequently than can be attributed to freak conditions. Apparently there is an impedance voltage drop in tower structures and grounding systems which accompanies heavy lightning discharges and which causes flashovers when the ohmic resistance drop appears low. As a practical consideration the effect has been evaluated in terms of tower currents.

For instance, on a 66-kv line having eight $4^3/_4$-inch insulators the upper limit for tower-footing resistance is obtained by substituting in the preceding equation

$$R = \frac{V}{I(1-CF)} = \frac{635{,}000}{150{,}000(1-0.25)} = 5.6 \text{ ohms}$$

It is assumed that 150,000 amperes is approximately the largest tower current that has ever been measured under natural lightning conditions. It would be logical to expect that towers having footing resistances of this level or less would not be subject to flashover; yet it has been found that flashovers have occurred on towers having footing resistance of this order of magnitude, when the indicated tower currents have been only about 60,000 amperes.[1] This leads to a modification of the desired level of tower-footing resistance based on economic considerations. With insulator flashover levels of about 600 kv, footing resistance can be considered the controlling factor for indicated tower currents up to only 60,000 amperes. Due to the uncertain

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terms of the percentage of time the set is in operation. In general the average savings exceed the average replacement cost.

Conclusion

The design and application of rectifier equipment using sealed ignitron tubes has involved the solution of many new and interesting problems. Light flicker, control, voltage regulation, the problems of excitation, overload, and arcback protection have necessarily formed a part of the evolution of this type of rectifier equipment. The basic problems have been solved, and it is believed that the continuous and reliable operation of the sealed steel-tube rectifiers will demonstrate that these electronic devices have the same high standards of performance as the older forms of conversion equipment.

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Table I. Optimum Tower-Footing Resistances for Several Transmission Lines

Line Operating Voltage (Kilovolts)	Suspension Insulator Units	Nominal 1½/sx40-Microsecond Flashover of Insulators (Kilovolts)	Optimum Tower-Footing Resistance (Ohms)
66	7–4¾ in.	565	5
66	8–4¾ in.	635	6
132	12–5¼ in.	1,015	10
220	20–5¼ in.	1,605	16

accuracy of tower-current measurements, it has been suggested that tower currents measured by surge-crest ammeter links mounted on tower legs be multiplied by a factor of 2 to correct for the currents carried by cross members of steel towers.[5] This gives a maximum safe tower current of about 120,000 amperes and a practical working value of about seven ohms for the optimum tower-footing resistance on an actual transmission line having an insulator flashover level of 635 kv. As all the factors in the equation are not known exactly under natural lightning discharge conditions, it has been found that a good working rule for the desired footing resistance is that it shall be not more than one ohm for each 100 kv of insulation flashover level, using the 1½/sx40 microsecond value. This is referred to as the optimum tower-footing resistance.

Some examples of optimum tower-footing resistances are given in Table I.

III. Selection of Counterpoise Length

Usually counterpoise is installed principally as a convenient auxiliary means for reducing tower-footing resistance. For this reason the amount of counterpoise conductor used is that required to bring the ground resistance as close as practicable to a desired level. There are some notable exceptions to this principle. The section of the Boulder Dam–Los Angeles lines in high resistance territory[6] and the High Knob section of the Wallenpaupack Tap[5] are published instances of effective counterpoise installations where ground-resistance criteria do not apply. It is significant that in both of these cases lines operate at high voltage and have high insulation levels.

Based on traveling wave theory, Bewley and Hagenguth[7] have suggested that counterpoise conductors should be no less than 200 feet long. This minimum length has proved to be a satisfactory one in the field, from the viewpoint of both installation and performance. The maximum length that has been used on the 66-kv lines considered in this paper has been 400 feet where spans are greater than 800 feet, and continuous from tower to tower where the spans have been less than 800 feet. On 132-kv and 220-kv lines where the insulation levels are higher (see Table I), continuous counterpoise has been installed where ground resistances could not be reduced sufficiently by buried conductors 200 to 400 feet long. The basis for this difference in procedure for the two classes of insulation levels is the observed phenomena that the 66-kv towers flash over when low measured ground resistances are due to good grounds at some distance from the tower bases,[1] and that the higher-voltage lines can apparently withstand heavy discharges even though the necessary low ground resistances are obtained only by counterpoise extending for some distance from the tower foundation.[5,8]

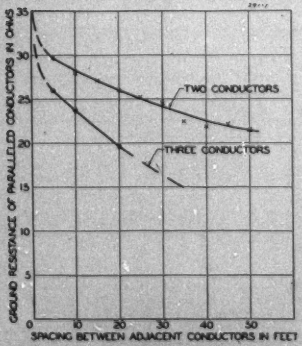

Figure 1. Effect of spacing on ground resistance of parallel buried conductors as determined by test

IV. Selection of Number and Spacing of Counterpoise Conductors in Parallel

Dwight[9] has published formulas for calculating the ground resistances of buried conductors, and they show that the greater the spacing between parallel wires the lower is the ground resistance of the system.

To indicate the practical limits for spacing, a set of measurements was obtained with seven 400-foot buried lengths of bare solid copper rod of one-fourth-inch diameter. The conductors were laid in straight parallel lines, 18 inches below the surface of the ground, five and ten feet apart. After a suitable weathering period, the resistances to ground of the individual conductors were 37, 37, 35, 35, 35, 30.5, and 32 ohms. The results plotted in Figure 1 emphasize the fact that two or more wires in parallel with reasonable spacings cannot produce so low a resistance as might be expected from the common relation for parallel resistances.

Table II. Reduction of Ground Resistance Due to Addition of Third Counterpoise Conductor Midway Between Two Others

Distance Between Two Outer Wires (Feet)	Ground Resistance in Ohms		Per Cent Reduction Due to Third Wire
	Two Outer Wires	All Three Wires	
10	28	26	7.1
20	26	23.8	8.5
40	21.8	19.7	9.6

Table II, based on the data of Figure 1, gives a comparison of the ground resistance of two parallel conductors with that of a set of three when a third conductor is installed midway between the original two. It can be seen that the third conductor reduces the ground resistance only slightly, but the reduction in the surge impedance would be greater theoretically than that in ground resistance.

Another investigation was made in the field to determine the relative merits of the installation of two counterpoise conductors parallel to each other on one side of a tower, as positions 1 and 2 in Figure 2B, and the installation of the two conductors on opposite sides of the tower, as in Figure 2A. Four wires, 540 feet long, were buried in the ground in the pattern shown in Figure 2B, with 26-foot spacing between parallel conductors. The ground resistances were as given in Table III, and show about a 25 per cent advantage for the arrangement of Figure 2A.

Based on field data, Table IV gives the order in which it has been found that

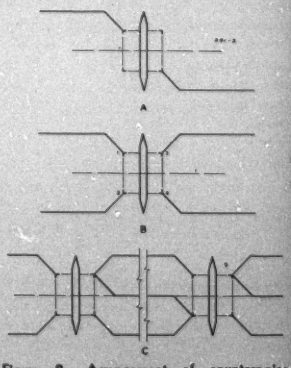

Figure 2. Arrangement of counterpoise conductors

Table III. Ground Resistance of Counterpoise Conductors at Test Installation Arranged as Shown in Figure 2B

Counterpoise Conductor Designations	Ground Resistances in Ohms
1	26.2
2	24.
3	25.3
4	26.9
1 and 2	18.5
3 and 4	18.8
1 and 4	14.1
2 and 3	13.2
All	10.1

counterpoise can be most effectively installed to reduce footing resistances to a desired level. The individual conductors are spaced as far apart as right-of-way restrictions allow, and the grounding conditions at each tower determine the type and extent of the counterpoise system to be installed.

V. Estimating Counterpoise Conductor Requirements

When tower foundations have been placed and a few weeks are allowed to elapse for the soil to settle around them, ground resistances are measured and used as indicators of the amount of counterpoise required. This procedure does not usually delay construction; when necessary, counterpoise can be laid and its resistance measured with a transmission line in operation. Incidentally, this fact has permitted counterpoise to be applied readily to the improvement of old lines. Tower-footing resistances have been found to be more reliable indicators of counterpoise requirements than spot soil-resistivity measurements, because of the abrupt changes in soil characteristics which occur in the territory under consideration. This territory varies from comparatively level ground, partly wooded, partly cultivated, up to hilly country where abrupt changes in elevation of a few hundred feet occur. Wherever rolling or hilly country is encountered, the soil consists of heavy clays liberally interspersed with broken shale or large boulders. In level country near sea level, the soil is generally sand or river silt.

Table IV. Recommended Order for Installation of Counterpoise Conductors

1. Two 200- to 400-foot conductors at opposite sides of tower (Figure 2A)
2. Four 200- to 400-foot conductors (Figure 2B)
3. Conductors extended to adjacent tower on one side, then to adjacent tower in opposite direction as required (see section III)
4. Third conductor laid midway between other two (Figure 2C)

It would be desirable to predetermine two characteristics of a counterpoise installation:

1. The levels to which ground resistances can be reduced from given initial tower-foundation resistances.

2. The amount of counterpoise conductor which will be required to attain the desired result.

No satisfactory method of doing either of these things was found until some actual field experience was accumulated. Based on data such as that given in section VII, estimates could be made of the average wire needed and final ground resistance to be attained for towers having foundation resistances in a given range. Even then, accurate estimates could not be made unless a large number of towers was considered, because the actual installation at a given tower frequently varied a good deal from the average result. Each tower and span was considered separately, taking into account situations in which long counterpoise conductors were required, and the installation would serve to improve conditions at both towers at the end of the span. In some cases it was found that certain towers would themselves require short counterpoise, while the neighboring tower would require a continuous one. An installation of this type, designed to make satisfactory the worse of two grounding conditions, would reduce the final ground resistance of the low-resistance tower much below the optimum value.

At those towers where large amounts of counterpoise conductor were called for, not more than three conductors in each direction from the tower were specified, because of considerations which were discussed in section IV.

VI. Ground-Resistance Measurements

A common method for making ground-resistance measurements is the three-electrode method.[10] With counterpoise conductors several hundred feet long, the required spacings of the two temporary probes used in the three-electrode method become impractically large. A simple and practical substitute for the three-electrode method is the direct reference method, using the completed transmission line and its grounds as the reference electrode.[10] The ground resistance measured by this method includes that of the reference electrode as well as that of the system being investigated. The ground resistance of an entire transmission line is usually only a fraction of an ohm, making the observed resistance the ground resistance of the counterpoise system for all practical purposes.

When applying the direct reference method, the counterpoise conductors are disconnected from the tower at which it is desired to obtain measurements and also from the next adjacent tower on each side, if the counterpoise is continuous. The counterpoise conductors are then electrically connected in parallel, and the resistance measured between their common point and the tower. The overhead ground wire serves to connect the tower to the rest of the system. It has been found by tests that the ground resistance of a counterpoise system and a tower in combination is approximately the same as that of the counterpoise system alone. The reason for this phenomenon is that the tower foundation lies within the extensive counterpoise system and does not contribute appreciably to the conductivity of the system as a whole.

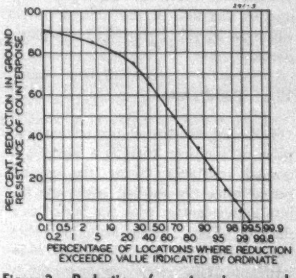
PER CENT REDUCTION IN GROUND RESISTANCE OF COUNTERPOISE
100
80
60
40
20
0
0.1 0.5 2 10 30 50 70 90 98 99.5 99.9
0.2 1 5 20 40 60 80 95 99 99.8
PERCENTAGE OF LOCATIONS WHERE REDUCTION EXCEEDED VALUE INDICATED BY ORDINATE

Figure 3. Reduction of counterpoise ground resistance due to weathering, at 483 tower locations

Counterpoise installed with a wire-laying plow

In this connection it is of some importance to note that the same effect is present when ground rods of moderate length are used at tower foundations. Due to the size of a tower foundation in relation to that of the rod and the small amount of additional soil contacted, the ground rod has been found to reduce ground resistances only slightly below that of the foundation alone. Exceptions occur in those special cases where a conducting stratum has been reached by rods of moderate length or very long rods have been driven.[11]

Practical considerations when making field measurements require that care be taken that corroded contacts do not cause inaccurate measurements. Defective electrical contacts may appear in the ground

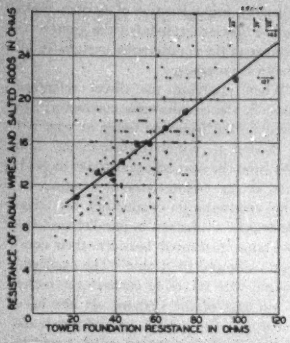

Figure 4. Ground resistances produced by four 50-foot buried radial wires terminating in salted rods at 171 locations on the Safe Harbor–Westport 220-kv line

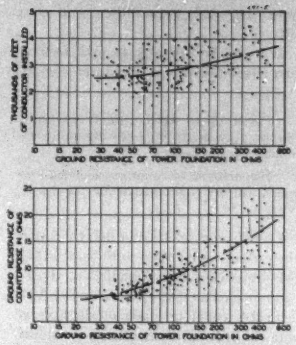
THOUSANDS OF FEET OF CONDUCTOR INSTALLED
GROUND RESISTANCE OF TOWER FOUNDATION IN OHMS
GROUND RESISTANCE OF COUNTERPOISE IN OHMS
GROUND RESISTANCE OF TOWER FOUNDATION IN OHMS

Figure 5. Counterpoise characteristics at 216 locations on the Holtwood–Coatesville 66-kv line

In many cases, counterpoise is continuous from tower to tower and serves to reduce ground resistance at two towers

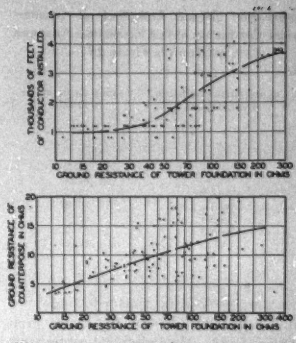
THOUSANDS OF FEET OF CONDUCTOR INSTALLED
GROUND RESISTANCE OF TOWER FOUNDATION IN OHMS
GROUND RESISTANCE OF COUNTERPOISE IN OHMS
GROUND RESISTANCE OF TOWER FOUNDATION IN OHMS

Figure 6. Counterpoise characteristics at 100 locations on the Safe Harbor–Perryville 132-kv line

The longer counterpoises are usually continuous and serve to reduce resistances at two towers

at bonded joints in the counterpoise conductors and also at the tops of towers where the overhead ground wires are supported.

VII. Field Data

Following the installation of counterpoise with a plow, there is a decrease in ground resistance during the ensuing period while the weather packs the soil into better contact with the buried conductor. This phenomenon has been found to be a highly variable one, indeterminate at any given location except by actual measurements of ground resistance. For instance, it can be seen in Table V that the variations in reduction have been from 0 to 91 per cent of the resistances measured at time of installation. After the initial weathering, further changes in counterpoise resistance have been found to be inappreciable. When making an installation, it has been the practice to allow for a reduction in ground resistance in order to limit the amount of wire used. In making this allowance, a balance was struck between an occasional installation of an excessive amount of counterpoise conductor as against the probable hazard of an occasional high footing resistance. In some cases where little or no reduction materialized, additional counterpoise was installed after weathering had occurred. Figure 3 can serve as a basis for establishing a working rule.

On the first line to which the principles of preventive lightning protection were applied, attempts were made to reduce the ground resistance of tower foundations by the addition of four 50-foot buried radial wires terminating in salted eight-foot ground rods. The results of this work are shown in Figure 4. In addition to the individual points shown on the graph, the encircled crosses each represent the average for 19 locations. This method of improving ground resistance was not satisfactory, because it did not reduce most of the tower-footing resistances below the desired level of 16 ohms. Subsequently footing resistances were improved by the addition of counterpoise conductor.

Figures 5 and 6 show the characteristics of counterpoise on two lines on which counterpoise alone was used to improve footing resistances. On the 66-kv line it was desired to obtain footing resistances below six ohms. On the 132-kv line the optimum value was ten ohms. As would be expected from the relative magnitude of the two desired final values, the economical maximum amount of wire which could be installed at a given location was reached more often on the 66-kv

Table V. Reduction of Ground Resistance of Counterpoise Due to Weathering at 483 Tower Locations

Per Cent Reduction $\left(1-\frac{\text{Final R}}{\text{Initial R}}\right)$	Tower Locations		Percentage Exceeding Maximum Reduction of Range
	Number	Percentage	
0	3	0.6	99.4
1– 5	3	0.6	98.8
6–10	2	0.4	98.4
11–15	7	1.5	96.9
16–20	6	1.2	93.7
21–25	15	3.1	92.6
26–30	12	2.5	90.1
31–35	15	3.1	87.0
36–40	27	5.6	81.4
41–45	35	7.3	74.1
46–50	33	6.8	67.3
51–55	36	7.5	59.8
56–60	44	9.1	50.7
61–65	36	7.5	43.2
66–70	43	8.9	34.3
71–75	39	8.1	26.2
76–80	62	12.8	13.4
81–85	45	9.3	4.1
86–90	19	3.9	0.2
91	1	0.2	0

Table VI. Summary of Counterpoise Installations Where Ground Resistances Were Measured After Weathering Occurred

Line	Number of Tower Locations	Ground Resistances in Ohms				Number of Locations Where Measured Exceeds Optimum	Feet of Conductor Installed Per Tower Location	
		Tower Foundation		Counterpoise				
		Maximum	Average	Optimum	Measured Maximum		Maximum	Average
Safe Harbor–Westport–Takoma (220 kv)	116	400	150	16	31	52	2,900	1,071
Safe Harbor–Riverside (220 kv)	234	450	77	16	18	8	4,650	1,172
Safe Harbor–Perryville (132 kv)	167	343	58	10	20	72	3,000	1,388
Holtwood–York (66 kv)	151	525	137	6	20	110	2,100	1,570
Holtwood–Coatesville (66 kv)	216	511	147	6	25	167	2,400	1,612

line than on the 132-kv line. It must be borne in mind that the lightning performance of these two lines is very good even though the optimum conditions were not attained in many cases.

The wide scattering of points in Figures 4, 5, and 6 are attributed to the abrupt changes in soil conditions which were frequently encountered. Where salted rods were used, they frequently could not be driven to their full length of eight feet due to rocky conditions. Where counterpoise was used, lower resistances to ground were obtained in cultivated fields and pasture land than in woods, and in low sections, than on hills. As the counterpoise was laid, it frequently would pass from one soil condition to another, producing noticeably different results on one side of a tower from those produced on the opposite side. In spite of the large variations in the results obtained at individual towers having similar foundation resistances, data of the type given have been useful in estimating the average requirements of projected installations.

It has not been the practice to remeasure the ground resistance of counterpoise at every location after weathering has occurred. It has been measured only at those locations where the values at time of installation were greater than the optimum values. For this reason complete data cannot be given for all locations on every line. However, in Table VI an indication is given of the magnitude of reductions in ground resistance that have been obtained by the use of counterpoise. The criterion of the worth of preventive lightning protection is the outage record of the lines to which it has been applied. Such a record is given in Table VII, and counterpoise has played an important role in minimizing interruptions due to lightning.

VIII. Summary

1. There is apparently an optimum value of tower-footing resistance for a given level of insulation on a transmission line. This has been evaluated empirically as approximately one-hundredth of the kilovolt flashover value of the insulation.

2. Three parallel wires in a counterpoise system seem to be the largest practical number. Such an installation provides six electrical paths away from a tower foundation.

3. The counterpoise system installed at each tower on a line must be graded to the conditions at the tower location if uniformly low ground resistances are to be obtained at reasonable cost. Uniform low ground resistances along a line are to be preferred to a uniform counterpoise system.

4. The ground resistance of a counterpoise system decreases for a period following installation due to settling of the soil around the buried conductors. After the initial weathering period, seasonal variations usually are small in the territory where observations were made.

5. The amount of counterpoise conductor installed and the final resistance obtained at towers having similar foundation resistance varied a good deal due to abrupt changes in soil conditions in the territory studied. In spite of the variations, the average results have been helpful in estimating conductor requirements for new work.

6. Preventive lightning protection, in which counterpoise plays a prominent part by reducing tower-footing resistances, is very effective in preventing flashovers on high-voltage lines.

Table VII. Lightning Outages of Lines Having Counterpoise as Part of Preventive Lightning Protection

Line	Years of Record	Outages	Outages Per 100 Miles of Line Per Year
Safe Harbor–Westport–Takoma (220 kv)	10	1	0.11
Safe Harbor–Riverside (220 kv)	4	1	0.50
Safe Harbor–Perryville (132 kv)	7	1	0.42
Holtwood–York (66 kv)	6	2	1.46
Holtwood–Coatesville (66 kv)	4	3	2.55

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Electric Control for Steam Boilers on Diesel-Electric and Straight Electric Locomotives

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ELECTRIC control is a necessity in the operation of the modern steam boiler if the boiler is expected to have maximum efficiency, safety in operation, and constant operation at the various outputs required. Installation and operating conditions vary over a wide range; therefore, to meet these conditions the controls used differ in type and quantity in order to supply those actually needed for good operation, as well as those required to comply with rules and regulations under which the installations are permitted. Generally, the method of operation of such boilers can be classified in two categories, namely, automatic and semiautomatic, and these two classes will be discussed in this article.

Electric control is further separated into two component parts, where one group of items consists of the operating necessities for actual boiler operation, and the other of safety features required under legal regulations (including those needed for the safety of the equipment itself in case of failure of any major part).

Automatic-Control Boilers

Operating Necessities

To analyze the operation and use of each of the control items used for a complete automatic installation, it will be advisable to start with the basic boiler and add each electric item in the order of its use for normal operation.

Current for igniting the atomized fuel is generally obtained from high-voltage transformers or magnetos, with the majority of installations using the transformer, because of its ability to give a very hot spark for complete combustion. With transformer ignition a source of alternating current is required, and this is obtained from a suitable rotary converter where the necessary direct current is taken from the locomotive batteries or control source.

To provide constant ignition under all operating speeds of the boiler motor—including the off cycle of the boiler when no steam is being used—the converter is connected directly across the line and is controlled by the master control switch. The rotary converter serves another purpose also by supplying alternating current for the electric-eye operation, which will be discussed later under safety controls.

The pressure switch, operating directly from steam pressure, actuates the balance of the controls to regulate the required output. Where various output capacities are required, a multifinger switch is used to vary the motor speed in accordance with steam output and it automatically cuts in the motor-speed relays to keep the steam pressure up to the operating point.

As less steam is used, the pressure switch causes the contact fingers to operate in a definite sequence to slow down the motor, and thus only sufficient steam is made to replace that amount which is being used. When the steam consumption becomes greater than the output, the contact fingers operate in the reverse cycle and cause the motor to speed up in order that sufficient steam should be available for the requirements.

Connected in the oil line is a solenoid valve used to stop the flow of oil when such operation is required. The valve coil receives its current from the main relay of the motor control and is only energized when the relay is closed and the motor running. During the off cycles of the boiler the motor relays are de-energized; therefore, the oil solenoid valve is closed to prevent any oil from collecting in the combustion chamber which might cause a minor explosion when the fire again lights. This valve is also kept de-energized when the main motor is being run, only for the purpose of filling the boiler with water, and is accomplished by an interlock in the master control switch.

An important item in electric controls is the time-delay relay which has several functions during the normal operation. When the boiler is ready to run, and the proper switches have been turned to their operating position, the time-delay relay is momentarily energized, but the contacts remain closed for a predetermined length of time. Unless the oil ignites and keeps burning during this predetermined time, the contacts will open and shut the boiler down. If the fire continues to burn, then the relay coil will become energized through the electric eye or stack switch operation. During the off cycles of the boiler, it is also necessary to keep this relay energized in order that the motor will again start when steam is required, and this is accomplished by an interlock on the motor relay or a separate pilot relay. The time-delay relay is generally adjustable, so that the predetermined time setting can be adjusted to suit the conditions required for various sizes and types of boilers.

Safety Features

On any boiler installation safety control features must be included in order to comply with laws or regulations, and also to insure safety in operation of the boiler itself. To provide some means of stopping the boiler in case the fire does not properly ignite or goes out because of some defective part of the controls, some means must be provided to detect this condition, and transmit the proper impulse to the motor controls. Two methods are generally used, one being the photoelectric-cell type and the other a stack switch whose contacts are operated by a bimetallic helix.

The photoelectric-cell method consists of locating the photoelectric cell so that it is affected by the oil flame in the combustion chamber, causing current to flow to the amplifying unit. The rectifying and amplifying unit used in conjunction with the photoelectric cell includes a sensitive relay that remains energized whenever the proper flame is burning in the boiler. If the flame should go out while the motor is still running, the sensitive relay acts on the time-delay relay, which will stop the motor after the predetermined time lag. During normal operation, where the pressure switch stops the motor and cuts off the flow of oil, a pilot-relay interlock keeps the time-delay relay energized even though the sensitive relay contact is open.

Stack-switch control is similar to the photoelectric cell except that the contacts are opened and closed mechanically by the bimetallic helix which is, in turn, affected by the temperature of the gas surrounding it in the smoke stack. These

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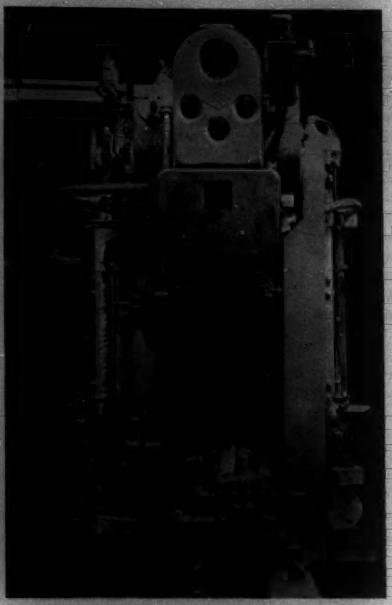

Figure 1. Front view of automatic steam boiler

Figure 2 (left). Side view of automatic steam boiler

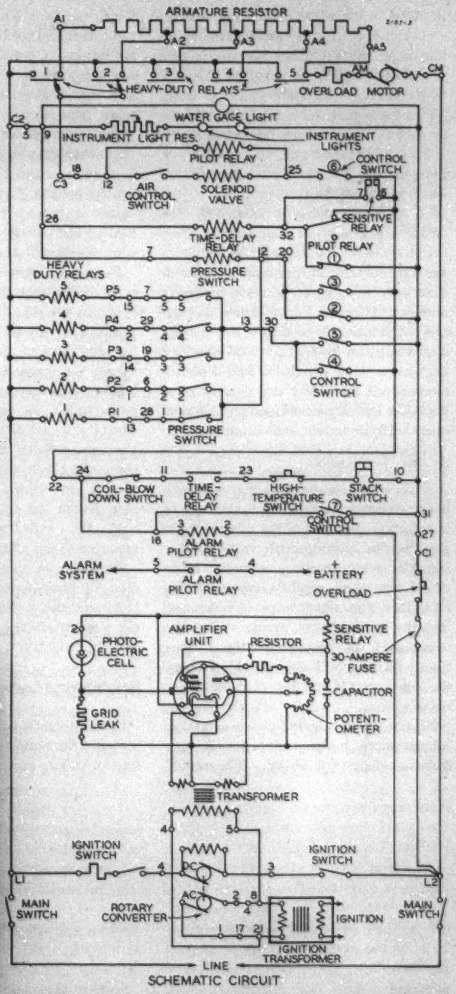

Figure 3. Schematic wiring diagram for described boiler

CONTROL SWITCH OPERATING POSITIONS

POSITION	1	2	3	4	5	6	7
TEST	●	●				●	●
OFF	●						
START				●	●		●
RUN				●	●	●	●

contacts are normally open and they close when a relatively low stack temperature has been reached such as one resulting from a continuous burning fire.

Where air, under pressure, is used to atomize the fuel oil, an air control switch is incorporated in the controls to insure that sufficient air of proper pressure is fed to the oil nozzle, so that the combustion will be complete and retain a clean fire. The air control switch is usually set to open the control circuit when a reduction of air pressure in the feed line reaches a point that will affect the combustion quantity of stack smoke and efficiency.

To protect against excessive high steam temperature, a high-temperature switch is incorporated in the control circuit to open the motor circuit when the temperature limit is reached. One type of switch uses an alloy that melts at this temperature and, in doing so, opens a spring set contact. To reset, the molten alloy must first cool and harden in order to hold the contacts closed for further operation of the motor controls.

A periodic blowdown of the coils is necessary to remove sediment and other foreign materials from the coils and pipe lines connected with them. To facilitate this operation a coil blowdown valve is

installed in the water intake line, and incorporated with it is an electric push-button assembly. When the valve is open the electric circuit is open, so that the boiler cannot run while steam is being blown back, and the boiler cannot be restarted until the valve is fully closed.

To guard against excessively high stack temperature, which is an indication of some faulty adjustment or badly sooted coils, a stack switch is located in the smoke stack, and its contacts are operated by a bimetallic helix. The high temperature contacts are normally closed and, once opened, have to be reset manually and only after the temperature has decreased sufficiently to enable the contact mechanism to re-engage. Installations that use a stack switch instead of photoelectric cell for a low fire control have both low and high temperature contacts operated by a common helix in one housing.

Alarm Mechanism

Audible or visual alarms are used with boiler controls, depending on the type of installation and rules of the operator. In general, the alarm circuit consists of a suitable relay whose contacts, when closed, ring a bell or light a series of lamps, or both. The alarm relay is connected into the boiler control circuit so that the opening of the contacts of the various safety features will not only shut down the boiler, but it will also give the designated alarm.

Figure 1 shows the front view of a typical automatic boiler equipped with controls as mentioned above. The multifinger pressure switch is shown to the right of the gauge box and in front of the air intake. Control cabinet directly below the gauge box contains the starting and speed-selection switch, time-delay relay, pilot relay and terminal-connection panel. The master motor for driving the blower wheel, water pump, and oil pump is shown mounted directly beneath the control cabinet. At the lower right-hand corner is shown a cutout box in which is located the electric push button used in conjunction with the coil blowdown valve.

Figure 2 shows the side view of the same boiler. At the upper left position is shown the side view of the multifinger pressure switch as previously described. To the right of the pressure switch is shown the ignition transformer and the high-voltage wires connected to the spark plugs which are near the top of boiler. The oil solenoid valve is shown directly at the top of boiler above the peep sight case. Just below the smoke-stack connection is shown the stack switch, mounted in the smoke hood, and to its right the high-temperature switch is mounted in the steam line.

Figure 3 is a schematic wiring diagram used in conjunction with this type of boiler and shows the connections between the various electrical operating controls and safety features.

Semiautomatic-Control Boilers

Semiautomatic-control boilers are essentially the same as the fully automatic-control boilers except for a few operating differences. The pressure switch is of the single-finger type, which opens and closes in accordance with the steam pressure selected but has no effect on the speed of the driving motor other than start and stop. Speed selections of the motor are made with a manual selector switch which connects to the motor various amounts of resistance, depending on the position of the switch. By this means the operator adjusts the motor speed, so that the steam output of the boiler will be satisfactory for the load it has to carry. Where motors used are of such size that motor starters are required, the necessary step control relays and starting resistance are needed in addition to the manual selector switch for actual speed-control setting.

Controls of this type are naturally limited to installations where the load is relatively constant for considerable lengths of time, or where an attendant is readily available to change the motor speed setting as often as necessary.

Electrical controls for steam boilers play such an important part in their operation, that any amount of time spent in developing the correct type is warranted by the practical results obtained. Full-time operation at maximum output and highest efficiency can be had only with electric controls that perform their respective functions in the way intended. The items mentioned in this article have been selected, from past experiences, to be necessary for proper operation and complete control of all functions of the boiler, including the safety requirements.

Electronics of the Fluorescent Lamp

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THE fluorescent lamp is one of the recent and rapidly growing additions to the field of electronic devices. In order to understand properly the characteristics of the fluorescent lamp, it is necessary just as with other electronic devices, to know something about the fundamental principles of operation. It is the purpose of this paper to describe the operating principles of this type of lamp, both as an electrical conductor and as a radiation generator. Following a brief outline of the properties of radiant energy as they concern lamp design, a description is given of the phenomena occurring in the separate regions of the lamp. The final section of the paper is concerned with the over-all characteristics of the lamp considered primarily as a circuit element.

The purpose of any electric lamp is to convert electric energy into radiant energy. The usefulness of a lamp depends not only upon the efficiency with which it converts the input energy into radiation, but also upon the suitability of the produced radiation for the particular application involved. The following description of radiant energy is presented to indicate requirements placed on a lamp as regards radiation output. In order to indicate the similarity of lamps to other electrical equipment, radiation is described in terms of frequency rather than by the more conventional wave-length designation. For the benefit of those more familiar with the wave-length description, important values are given in both units.

Radiant Energy

To be useful as light, the radiant energy produced by a lamp must fall within the region of the spectrum to which the human eye is sensitive. This region is shown in relation to the remainder of the electromagnetic spectrum by the chart of Figure 1. Although the ultraviolet and infrared regions of the spectrum immediately adjacent to the visible are not directly useful for illumination, they are increasing in importance for other uses, and the term lamp has been extended by common usage to include sources of radiation in these regions of the spectrum. The range of frequencies covered by commercially available lamps is shown in the expanded portion of Figure 1.

It is desirable to control the processes of energy conversion within a lamp so that the proper frequency of radiation is obtained for each intended application. This may be illustrated for visible light by the curve of Figure 2, which shows the average response of the light-adapted human eye as a function of frequency. This may be compared with the response of a radio receiver tuned to a frequency of 540×10^{12} cycles per second, corresponding to a wavelength of 5,550 angstrom units (A). It is apparent that the greatest possible light-producing efficiency would be obtained with a lamp which converted all the energy input into radiation at this frequency. Such a lamp would be a green light source having an efficiency of approximately 620 lumens per watt. However, the usefulness of such a lamp would be limited because of its color. When a lamp produces radiation at any frequency other than 540×10^{12} cycles per second, its luminous efficiency is necessarily lower than the above value. For example, a lamp which converted all the input energy into radiation within the visible region having the same spectral distribution as average daylight would have a luminous efficiency of only 220 lumens per watt.

In the incandescent lamp, the spectral distribution of the output radiation is continuous throughout the spectrum and is controlled by the operating temperature of the filament. Since the energy distribution is continuous, it is not possible to confine the output to a narrow range of frequencies, except by filtering out and thus wasting the undesired radiation. In a gaseous discharge lamp the frequency of the output radiation is fixed by the kind of gas, each gas having certain characteristic frequencies which it can radiate. The relative amounts of energy radiated at the different frequencies can be controlled by the type of discharge. A good example of this method of control is given by two types of mercury lamps: in the low-pressure germicidal lamp most of the radiation from the mercury is concentrated in the short-wave ultraviolet, while in the high-pressure capillary lamp a major portion of the radiation is produced in the visible and long-wave ultraviolet regions. In the fluorescent lamp the output frequency is controlled by the choice of the fluorescent coating, as will be described later in this paper. However, the operation of the fluorescent lamp also involves a gaseous discharge in which, as in the simple discharge lamp, the most important controlling factors are the nature of the gas and the type of discharge. The electronics of the fluorescent lamp are concerned with the operation of this gaseous discharge, both as a circuit element and as a radiation generator.

Principle of the Fluorescent Lamp

The process by which the fluorescent lamp converts electric energy into visible radiation is analogous to that of two energy converters connnected in series. The first of these is a gaseous conduction lamp which is designed to convert electric energy into ultraviolet radiant energy. This lamp usually takes the form of a glass tube having a length of from 10 to 50 diameters. Within the tube is a small drop of mercury producing a mercury vapor pressure corresponding to the temperature of the tube wall. Also present is a low pressure of argon gas. Specially designed electrodes at each end of the tube are connected to the external circuit by means of vacuum-tight glass-to-metal seals. In operation this constitutes a low-pressure mercury vapor discharge lamp which can be made to convert 50 per cent or more of the electric energy input into ultraviolet radiation of wavelength 2,537 angstrom units corresponding to a frequency of $1,182\times10^{12}$ cycles per second.

The second energy converter in the fluorescent lamp is a frequency changer which converts the $1,182\times10^{12}$ cycles per second radiation into visible radiation with frequencies between 750 and 430×10^{12} cycles per second (4,000–7,000 angstrom units). This frequency converter consists of a coating of fluorescent powders which is applied to the inside surface of the discharge tube. This frequency conversion process is relatively high in efficiency so that, when it is combined with an efficient source of the exciting radiation, a high over-all lamp efficiency is produced.[1,2] Although a major portion of this paper is devoted to the gaseous conductor, a brief description of the characteristics of fluorescent powders is necessary in order to illustrate the require-

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ments which the gaseous conductor must meet.

Fluorescent Materials

Certain materials, known as phosphors,[3] have the property of emitting visible light when they are exposed to exciting agents such as cathode rays, X rays, and ultraviolet radiation. The light thus produced is called fluorescent light, and most engineers are familiar with this property as used in the fluorescent screen of the cathode-ray oscilloscope and the X-ray fluoroscope. However, by far the most efficient method of exciting these phosphors is the use of ultraviolet radiation, as in the process used in the fluorescent lamp.

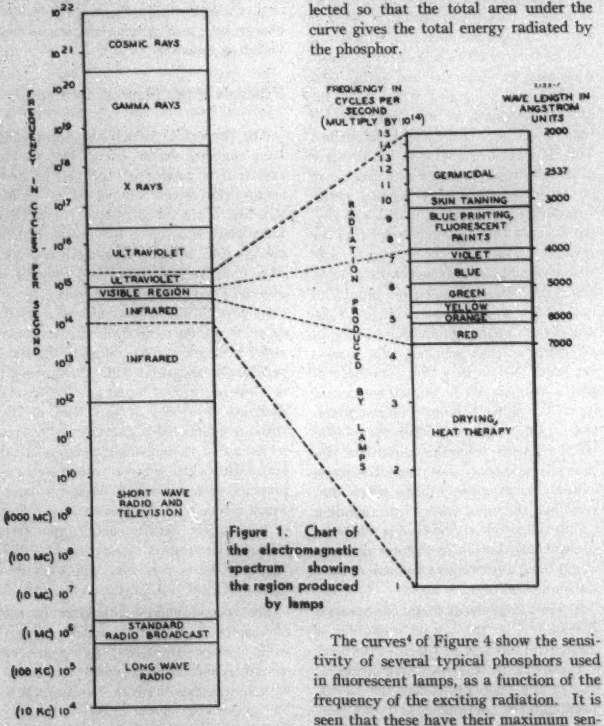


Figure 1. Chart of the electromagnetic spectrum showing the region produced by lamps

The color of the fluorescent light depends upon the type of phosphor and the methods by which it is prepared and is not, in general, influenced by the frequency of the exciting radiation. Table I lists some of the phosphors used in fluorescent lamps and gives the predominant color of the light which they emit. By properly mixing these different phosphors, one can obtain almost any desired color of light. The curves of Figure 3 show the distribution of the energy output with respect to frequency for daylight, blue, and pink fluorescent lamps. The continuous curves represent the energy radiated from the phosphor; the dotted rectangles represent the relatively small amount of visible energy produced by the mercury discharge.[4] It should be pointed out that the curves given in Figure 3 are plotted with respect to frequency, and they therefore differ in shape from curves plotted with a uniform wavelength scale. Ordinates have been selected so that the total area under the curve gives the total energy radiated by the phosphor.

The curves[4] of Figure 4 show the sensitivity of several typical phosphors used in fluorescent lamps, as a function of the frequency of the exciting radiation. It is seen that these have their maximum sensitivity in the region near $1{,}182 \times 10^{12}$ cycles per second (2,537 angstrom units), which is the radiation most efficiently produced by the low-pressure mercury discharge which makes up the gaseous conductor of the fluorescent lamp.

The Gaseous Conductor

A glass tube filled with neutral gas atoms, as, for example, an unexcited fluorescent lamp, is an almost perfect insulator. Even if electrons are freely introduced into the gas, only small currents can be made to flow with the usually available voltages, so long as the gas atoms remain electrically neutral. The reason for this is that the space charge produced by the electrons limits the flow of current. Only by breaking up the atoms of the gas into charged particles, or in other words, "ionizing" the gas, can reasonably large currents be made to flow. This process of ionization is essential to the operation of almost every type of gaseous conductor. In the case of a rectifier, thyratron, or similar device, the passage of current is the chief function of the discharge, and conditions are preferably arranged so that a minimum amount of energy is absorbed by the conductor. The primary purpose of the gas discharge lamp, on the other hand, is to produce radiation. As will be described later in the paper, radiation is obtained from "excited" atoms which have absorbed energy from the discharge. Hence, in the discharge lamp, conditions are preferably arranged so that as much energy as possible is absorbed by the conductor in the formation of excited atoms.

The gaseous conductor of the fluorescent lamp may be separated into three main regions, namely, the cathode region, the anode region, and the positive column. The most important of these is the positive column, which includes most of the length of the lamp, and in which most useful excitation (and hence radiation) is produced. The cathode and anode regions serve to connect the positive column to the external circuit. These are regions of low light-producing efficiency and, for this reason, conditions in general are chosen so that they consume as little as possible of the total lamp wattage. On alternating current the same electrode structure must serve alternately as anode and cathode, although the electronic phenomena are greatly different for the two functions. Before considering in detail these regions of the discharge, a brief description will be given of the fundamental processes of excitation and ionization.

Excitation and Ionization

Although there are many ways in which atoms may be excited and ionized, in a gas discharge lamp, we are primarily interested in excitation and ionization by electron collision. For the purposes of our description an atom may be pictured as a positively charged nucleus surrounded by a number of electrons. The mass of the nucleus is very heavy compared to that of an electron. In the normal state of the atom, the number of electrons is just

sufficient to neutralize the positive charge of the nucleus and in addition the internal energy of the atom is at its minimum value. If this normal atom is struck by an electron, the collision may be as between elastic spheres, and, due to its great mass, the atom will absorb very little energy from the electron. The small amount of energy which is absorbed in such a collision appears as a change in velocity of the atom (increase in thermal energy of the atom). If, however, the colliding electron possesses more than a certain minimum amount of energy, there exists a probability that the atom will make an inelastic collision and absorb a definite amount of energy from the electron. In this process one (in rare

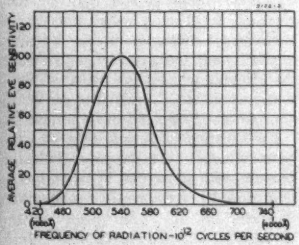


Figure 2. Average relative response of the light-adapted human eye as a function of frequency

cases more than one) of the electrons of the atom is changed from its normal state to a state of higher potential energy, and the atom is said to be "excited." In the new state the electron is more loosely attached to the nucleus but is still a part of the original atom; hence, an excited atom is still electrically neutral. For each different kind of gas atom certain characteristic discrete states of potential energy are possible, and these are usually called energy levels. An atom does not remain in an excited state indefinitely, but in most cases very quickly returns to the normal state and releases the energy of excitation in the form of radiant energy. The frequency of the radiation emitted during the transition from one level to a lower level depends upon the energy difference between the levels, and is given by the equation:

$$f = 242.9 \times 10^{11} V \text{ cycles per second} \qquad (1)$$

where f is the frequency of the emitted radiation and V is the energy difference expressed in electron-volts (an electron-volt is the energy gained by an electron in traversing a potential difference of one volt). When several possible energy levels lie between a given excited state and the normal state, this transition may occur in several steps.

The lowest energy level (neglecting metastable states) from which a mercury atom can return to the normal state corresponds to an energy difference of 4.86 electron-volts. This transition, by equation 1, produces radiation at a frequency of $1{,}182 \times 10^{12}$ cycles per second, which is the radiation desired for exciting the phosphor in the fluorescent lamp.

Ionization is a process similar to excitation except that the energy absorbed by the atom in question is sufficient completely to remove one or more of its electrons. An atom which has lost an electron is positively charged and is known as a positive ion. Ionization may be produced in one step, if the colliding electron has energy greater than a certain value known as the minimum ionizing potential. This value for mercury is 10.38 electron volts. Other types of ionizing collisions exist, but there is evidence that they are

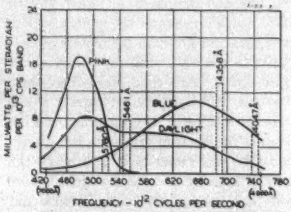


Figure 3. Spectral distribution of radiation from 15-watt fluorescent lamps of different colors

of lesser importance under the conditions of the fluorescent lamp.

The manner in which these fundamental processes of excitation and ionization are utilized in a fluorescent lamp will now be considered.

The Cathode Region

The cathode in a fluorescent lamp is of the type commonly known as oxide-coated (or Wehnelt) and consists of a coil of tungsten wire activated by means of a coating of alkaline-earth oxides such as barium and strontium oxides. During starting, the cathode is preheated, and for this purpose two external leads are provided to permit passage of the heating current directly through the cathode coil. After starting, the discharge provides sufficient heating of the cathode, and external heating is not required.

In normal operation only a small portion of the cathode area is heated by the discharge to an electron emitting temperature, and the available zero-field emission current is considerably less than the total lamp current. Under these conditions a positive-ion space charge builds up at the cathode and produces an electric field at the cathode surface. The region of high electric field is called the cathode sheath. This field very greatly increases the electron emission in a manner which is characteristic of activated surfaces.[5] The generally accepted picture of the cathode phenomena under these conditions is as follows.[6]

Electrons emitted by the cathode are accelerated by the field which exists in the above-mentioned positive-ion cathode sheath. The voltage drop across this region is known as the cathode fall and has a value slightly larger than the minimum ionizing potential of the gas which surrounds the cathode. The electrons from the cathode thus acquire energies capable of ionizing and exciting the atoms with which they collide in the region beyond the positive ion sheath. The positive ions produced in this region diffuse in all directions, and those moving toward the cathode counteract the space charge of the electrons and create the field of the cathode as described above. Because the positive ions have masses

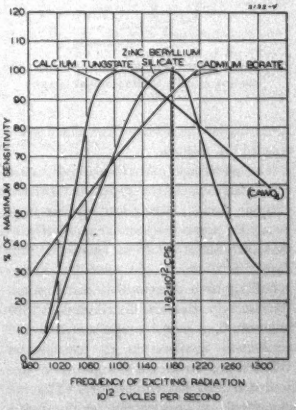


Figure 4. Relative sensitivity of typical phosphors used in fluorescent lamps, as a function of frequency of exciting radiation

many times greater than the electrons, they move much more slowly, and therefore relatively few are required to counteract the space charge of the electrons. In the case of mercury, the relative velocities of an electron and a positive ion, both having the same energies, are approximately 600 to 1.

An approximate calculation of the

zero-field emission current under actual lamp-operation conditions will serve to illustrate the order of magnitude of the quantities involved. For an eight-watt lamp cathode operating at 0.18 ampere, observed values of emitting area and temperature are approximately 0.01 square centimeters and 1,180 degrees Kelvin, respectively. Using the data given by Dushman,[7] the zero-field emission current is calculated to be 0.75 ampere per square centimeter, giving a total current of 0.007 ampere. Thus, for the particular conditions here described, the zero-field emission is only about four per cent of the total lamp current. This figure agrees in order of magnitude with the value of ten per cent given by Found[6] for a similar type of cathode. That the observed current is so much greater than this zero-field value is explained by the above-mentioned action of the electric field at the cathode. In addition a small fraction of the current

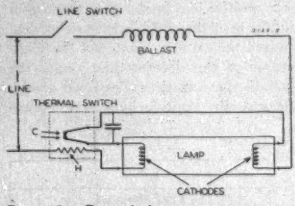


Figure 5. One of the common automatic starting circuits for fluorescent lamps

is carried by the positive ions which move toward the cathode.

The electrons from the cathode, after producing ions in the region beyond the cathode sheath, have relatively low energies. By some mechanism not well understood, these electrons acquire a random distribution of velocities corresponding to a Maxwellian distribution. (When velocities are distributed in this manner, they may be represented by an equivalent temperature T_e, just as the velocities of the atoms of a gas are represented by the gas temperature. Thus we can speak of an electron temperature.) These low-energy electrons and the positive ions both diffuse from the cathode glow region and after a short distance enter a region where the voltage gradient begins to rise. This is where the positive column begins.

The Positive Column—Conduction Processes

The positive column is a region characterized by a uniform voltage gradient and a uniform degree of ionization throughout its length. Electrons entering from the cathode region gain energy from the gradient along the tube but nevertheless maintain a Maxwellian distribution of velocities, which corresponds to a temperature greater than that of the entering electrons, and which is many times greater than the temperature of the gas. These electrons drift toward the anode under the influence of the longitudinal gradient and, because they move faster than the positive ions, constitute all but a negligible fraction of the discharge current. This drift velocity of the electrons is small compared with their random velocities. In moving through the gas, these electrons collide with atoms of the gas, and some of these collisions result in the formation of positive ions and additional electrons. The electrons and positive ions have essentially equal concentrations in the positive column, and both diffuse toward the wall. As a result of their smaller mass, the electrons have higher velocities and tend to diffuse faster than the positive ions. This difference in rate of diffusion produces a radial electric field which accelerates the motion of positive ions and slows up the motion of electrons to the wall, until the two rates are just equal. This condition is necessary, because obviously the net current to the wall must be zero. It is apparent that the greater the electron velocities, the greater must be this radial field, and hence the greater must be the rate at which positive ions are lost to the wall. Tonks and Langmuir[8] have developed a relation called the plasma balance equation which expresses the rate at which ions are lost to the tube wall as a function of the electron temperature.

Not only is the rate at which ions are lost to the tube wall dependent on electron temperature, but also the rate at which they are generated is a function of the electron temperature. This follows from the fact that the probability that an electron will produce ionization by collision increases with the energy of the electron in excess of the minimum ionizing energy. (For very high energy electrons this probability decreases again.) This probability can be measured and is known for mercury vapor.[5] Thus it is possible to calculate the rate at which ions will be produced in a gas by electrons having any given electron temperature.[9]

In the steady state, for the type of discharge used in the fluorescent lamp, the rate at which ions are produced must equal the rate at which they are lost to the tube wall. Therefore the equations expressing the rate of ion generation and the rate of ion loss can be equated as shown by Found.[10]

$$(2V_T+V_i)e^{-V_i/V_T}=\frac{0.9\,s_g}{B\,a}\frac{T_g}{P_g}\left(\frac{m_g}{m_p}\right)^{1/2} \qquad (2)$$

where V_T is the voltage equivalent of the electron temperature, V_i the minimum ionizing potential of the gas, s_g is a factor dependent on the geometry of the container and the gas pressure, a is the tube radius, B is a constant relating to the probability of ionization which can be measured for any given kind of gas, T_g and P_g are respectively the temperature and pressure of the gas within the tube, and m_e and m_p are respectively the mass of an electron and the mass of a positive ion of the gas. From this equation it is possible to calculate the electron temperature for a tube containing a given gas at a known pressure by means of known constants. It can be seen that for any given gas the electron temperature (electron energy) decreases with an increase in tube radius and gas density and that the electron temperature remains constant as long as the product of gas density and tube radius remains constant.

This equation does not describe the experimental fact that the tube gradient decreases with an increase in arc current. This property of the positive column of

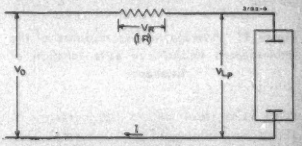


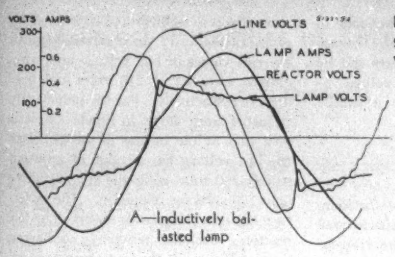
Figure 6. Simple resistively ballasted operating circuit

the fluorescent lamp is accounted for partly by an increase in mercury vapor pressure with an increase in input watts. In addition, Tonks and Langmuir[8] propose the explanation that two-stage ionization processes would permit lower energy electrons to produce ions and would therefore require a lower electron temperature than is needed for single-stage ionization conditions.

As was stated above, the positive ions are produced in the positive column only by the higher-velocity electrons in the Maxwellian distribution. This fact is of great importance in the production of radiation from a gas discharge lamp.

The Positive Column—Radiation Generation

In order to obtain a sufficient number of high-velocity electrons to satisfy the need for positive ions in the positive column, it is necessary (because of the Maxwellian distribution of velocities) to create a much larger number of lower-velocity



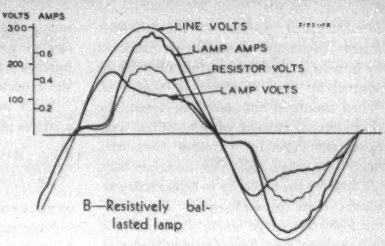


Figure 7. Oscillograms of current and voltage for two types of ballast

electrons. For example, if the average energy of the electrons is two electron volts, only 1.5 per cent of the total number have energies above the minimum ionizing potential of mercury, while 18 per cent have energies greater than the minimum excitation potential of mercury. Thus the process of radiation generation is only indirectly the result of the passage of current through the discharge tube. It follows that in order to increase the amount of radiation at any given frequency it is necessary to adjust the conduction processes so that the resulting electron energy approaches an optimum value for exciting the gas atoms to the desired energy level. In the practical lamp ideal conditions cannot be reached, because of considerations regarding total light output for a given size of lamp and other factors which cannot be considered here, relating to the lamp as a light source rather than as an electronic device.

The Anode Region

The anode region serves to connect the positive end of the positive column to the external circuit. Conditions at the anode are similar to those at the tube wall, except that the electron current reaching the anode must exceed the positive ion current by an amount equal to the current through the tube. If the anode area is large enough, so that the rate at which the electrons strike it as a result of their random motions is equal to the discharge current, no anode drop is necessary. If the anode area is larger than this, it develops a negative voltage with respect to the gas and repels electrons, until the net current reaching it just equals the tube current. If the anode area is too small, it develops a positive voltage with respect to the gas and attracts electrons until the net current collected is equal to the drift current. In this case a sheath builds up around the anode, until the electron current entering the sheath is equal to the discharge current. The area of this sheath is then the effective anode area. By convention, a positive anode drop means an increase in tube volts. In the fluorescent lamp, the anode area is such that the average anode drop has a positive value of approximately seven volts. This value is primarily determined by the requirements of cathode heating.

Electrode Heating

No mention has been made of the manner in which cathode is heated, except to state that this is done by the discharge. This process will now be discussed more in detail. On alternating current, each electrode functions alternately as anode and as cathode. During both half cycles, heat is removed by conduction and radiation, and a small amount of heat is produced by the passage of current through the cathode coil. During the cathode half cycle an additional loss of heat occurs as a result of the evaporation of electrons from the cathode, and at the same time heat is gained from the positive ions which reach the cathode. On the anode half cycle heat is supplied by the electrons, which are accelerated through the voltage drop in the anode sheath and deliver this energy—in addition to their thermal energy and the heat of condensation—to the electrode. This is the most important source of electrode heating in a-c operation. The total net heating is the average of that produced on the two half cycles, and in the usual fluorescent lamp this is more than sufficient to raise the cathode to an operating temperature. In fact, it is usually necessary to attach projections to the electrode to reduce the amount of heat gained on the anode half cycle, in order to prevent evaporation of the cathode material.

Over-All Characteristics of the Fluorescent Lamp

Like most electronic devices the operation of the fluorescent lamp is greatly influenced by the characteristics of the circuit to which it is connected. Consequently, any description of lamp characteristics must be made with reference to a particular set of circuit conditions.

For reasons to be described in this section, the fluorescent lamp cannot be satisfactorily started and operated unless the line voltage is greater than the lamp voltage. Consequently a voltage-absorbing device must be connected in series with the lamp to absorb the difference between the two. This necessary difference between lamp voltage and line voltage is the determining factor in selecting the amount of ballast required. Commercially this ballast consists of a resistance for d-c operation, while on alternating current it may be a resistance, an inductance, or a combination of inductance and capacitance. The commonly made statement that a ballast is required because of the negative volt-ampere characteristic of the lamp is true, but there are other equally important reasons for its use. These reasons are, as will now be described, the need for lamp starting, the need for good regulation with changes in line voltage, and the need for good current wave shape on a-c circuits.

Lamp Starting

In order to start a fluorescent lamp, it is necessary to ionize the gas between the electrodes and to heat the cathodes to an electron-emitting temperature. Perhaps the simplest method of accomplishing this is to apply a voltage several hundred volts in excess of the normal lamp-operating voltage across the lamp terminals. With this method of starting, however, the cathodes are required to emit electrons before the discharge has time to heat them to an emitting temperature, and the resulting high cathode drop may produce destructive sputtering of active material from the cathode surface. Also a disadvantage of this method of starting is the fact that the size and wattage loss of the ballast are greater than would otherwise be required. Conventional starting circuits avoid these difficulties by the use of a switch which connects the cathodes in series with the ballast, so that they are adequately preheated, and then opens the circuit to provide an inductive surge to start the lamp. The circuit of Figure 5 shows a thermal switch arrangement used

for automatic starting of the 100-watt fluorescent lamp. Contacts are mounted on bimetallic elements, so that they can be opened by heat produced in heater H. When the main line switch is closed, the short-circuit current of the ballast preheats the cathodes. Heater H is connected in series, and after time has been allowed for the cathodes to be heated, contacts C-C are caused to open. The resulting inductive surge starts the lamp, and lamp current then flows through heater H, keeping the contacts open. This starting action may also be accomplished by means of a glow switch.[11] In the case of direct current, if the ballast consists of a resistor, no inductive surge is produced when the switch opens. This difficulty is overcome by using a series inductance which does not contribute to the ballasting, but which supplies the necessary inductive starting surge.

Operating Stability

On a perfectly regulated line, a fluorescent lamp would theoretically require a ballast just sufficient to offset the negative volt-ampere characteristic of the arc, and the lamp voltage could be made nearly equal to line voltage. In a practical circuit, however, the ballast must be greater than this value, in order to take care of normal variations in line voltage.

This fact can be demonstrated by the following approximate analysis of a resistively ballasted lamp. Over the normal range of operating currents, the lamp voltage changes by only a small amount and consequently can be treated as a constant. Referring to the circuit of Figure 6

$$V_o = V_{Lp} + IR \text{ and } IV_{Lp} = \text{lamp watts} = W_{Lp}$$
$$dV_o = R dI \text{ and } dW_{Lp} = V_{Lp} dI$$

Expressing the change in watts as a fraction of the total lamp watts

$$\frac{dW_{Lp}}{W_{Lp}} = \frac{V_{Lp} dI}{V_{Lp} I} = \frac{dI}{I} = \frac{dV_o}{IR} = \frac{dV_o}{V_o} \frac{V_o}{IR} = \frac{dV_o}{V_o} \frac{V_o}{(V_o - V_{Lp})}$$

From the above equations we see that, if the lamp voltage were half the line voltage five per cent change in line voltage would produce a ten per cent change in lamp wattage, while if the lamp voltage were two-thirds the line voltage, a five per cent change in line voltage would produce a 15 per cent change in lamp wattage. How nearly the lamp voltage may be made to approach line voltage is limited by the permissible variation in lamp watts and by the expected variation in line voltage.

With an inductive ballast a similar analysis gives the relation

$$\frac{dW_{Lp}}{W_{Lp}} = \frac{dV_o}{V_o} \cdot \frac{V_o^2}{(V_o^2 - V_{Lp}^2)}$$

so that on this type of ballast the lamp voltage may be made to approach more nearly the line voltage for the same regulation than is the case with resistive ballast. In practice the wattage changes are greater than shown here, because the lamp voltage decreases with an increase in current. For most commercial ballasts the ratio of line volts to lamp volts is approximately 2 to 1.

Table I. Phosphors Commonly Used in Fluorescent Lamps[4]

Phosphor	Frequency, in 10^{13} Cycles Per Second of Maximum Radiation Output	Wavelength, in Angstrom Units, of Maximum Radiation Output	General Color
Calcium tungstate	680	4,400	Blue
Magnesium tungstate	625	4,800	Blue-white
Zinc silicate	570	5,250	Green
Zinc beryllium silicate	505	5,950	Yellow-white
Cadmium borate	484	6,150	Red

In addition to resistive and inductive ballast, a third type of ballast is used in commercial circuits. This consists of a combination of an inductance and a capacitance connected in series. This type of circuit has a more nearly constant current characteristic, and it is possible to operate the lamp more nearly equal to line voltage. Such circuits are usually used in conjunction with inductive ballasts, and the regulation of the inductive ballast controls the choice of line voltage as explained above.

Wave Shape

On alternating current it is necessary also to consider the requirements of wave shape of current and voltage. This results from the fact that on alternating current the lamp must be reignited on each succeeding half cycle. The type of ballast has an important influence upon the wave shape, as is illustrated by the oscillograms of Figure 7. In both oscillograms the rms values of line voltage and lamp current were set at 210 volts and 0.42 ampere respectively. For the inductively ballasted lamp shown in Figure 7A, it is seen that at the instant of current zero the line voltage has a value of approximately 250 volts, while the lamp requires only 150 volts for reignition. The difference between these two is absorbed by the reactor. For the resistively ballasted lamp of Figure 7B the lamp current is in-phase with the voltage, and consequently zero voltage is available for reigniting the arc at the instant of current zero. The current therefore remains at a low value for a period of approximately 20 degrees before reignition takes place. Due to this long wait, deionization of the positive column has begun to take place, so that 175 volts are required to reignite the arc.

A similar lag in reignition may occur on inductive ballast, if the line voltage is not sufficiently greater than the lamp voltage. The type of current wave shape shown in Figure 7B is not so desirable as that of Figure 7A, because of increased flicker, or stroboscopic effect, due to the extended period of zero current.

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Regulated Rectifiers in Telephone Offices

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MEMBER AIEE

FOR many years rectifiers of the garage type were used in converting alternating current to direct current for charging batteries used for communication purposes. These batteries furnish power for relay operation, for talking, and filament and plate supplies for repeaters. The rectifiers were of the manual-control type where the operator selected the charging current by means of tap switches or rheostats.

With the development of the thyratron type of tube, a rectifying means was made available in which the grid of the rectifier tube could be used to control its own output current by an electronic circuit. Rectifier circuits were designed to maintain a constant output voltage. If a regulated rectifier is connected to a battery and the constant rectifier voltage is 2.15 volts per cell, the load current will automatically come from the rectifier and not from the battery. Also the battery will draw from the rectifier sufficient additional current

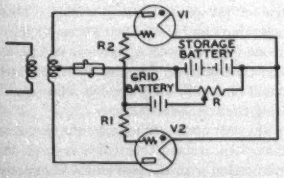
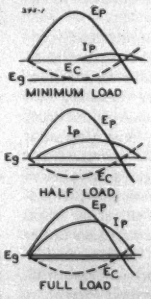


Figure 1. Magnitude control circuit

to maintain its charge. If the circuit voltage is held within limits of less than plus or minus one per cent, the maintenance of the battery is reduced and its life is extended.

The thyratron tube differs from the vacuum tube in that the grid does not have a continuous control of the plate current.[1] When a positive potential is applied to the plate, current does not flow until the magnitude of the negative grid voltage is reduced to the critical value, at which time the plate current flows, and the magnitude of the plate current depends upon the voltages and impedances in the circuit. The grid has no further control, and plate current flows until it is stopped by reducing the plate voltage to zero.

Thyratron tubes use various gases and mixtures of gases. The earliest type used mercury vapor, but this type of tube is quite sensitive to temperature changes. The grid characteristics are shifted materially by changes in the room temperature in which it is operated, and in low temperatures it is almost a vacuum tube. Thyratron tubes using argon gas are not affected by temperature changes, but high-pressure argon tubes have a higher inverse voltage which limits their application to low-voltage rectifiers. Tubes using low-pressure argon have a higher inverse voltage, but are accompanied by a high arc drop which makes their efficiency low. A mixture[2] of mercury vapor and argon has been found which provides the temperature-stable grid characteristic of the argon tube and the low arc drop of the mercury-vapor tube. This type of tube has been very successful with certain regulating circuits, particularly at voltages less than 60 volts.



Five kinds of regulating circuits are used in telephone offices to hold the output voltage of rectifiers constant. The selection of the circuit to be used depends upon the magnitude of the current, d-c voltage, and type of rectifying means to be used. Two forms of regulating circuits using thyratron tubes and one using two-element high-pressure tubes were developed. A fourth circuit using all vacuum tubes was adapted for telephone use. The fifth kind uses a negative resistance.

Magnitude Control

The automatic regulating circuit using the temperature-stable tubes has been called the magnitude method[3] of control, since the voltage applied to the grid is a d-c voltage, and its magnitude is varied to control the plate current of the tube.

Figure 1 shows a schematic circuit and diagrams of the voltages applied to the rectifier tube. The rectifier circuit is the conventional full-wave circuit with a filter coil in the negative output lead. A negative voltage, with respect to the tube cathodes, is taken off a potentiometer connected across the battery to be floated. This negative voltage is opposed by a slightly smaller positive voltage of a grid battery. The net negative voltage of a few volts is applied to the grids of the tubes through grid resistances. The top diagram in Figure 1 shows the positive half of the a-c voltage applied to the tube. The dotted line represents the critical grid voltage of the tube, *Ip* the plate current that flows, and *Eg* the d-c grid voltage applied to the grids. If the applied grid voltage is more negative than the critical value, the tube does not fire and no plate current flows. If the magnitude of the grid voltage is decreased until it reaches the critical value, the tube fires and the rectifier delivers output. A further decrease in the grid voltage will result in the critical value being equaled earlier in the cycle, and the average value

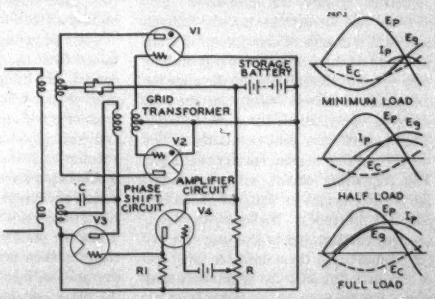


Figure 2. Phase-shift control circuit

of the plate current will increase. Finally, with the grid voltage zero, the tube fires at the beginning of the cycle and the maximum average value of current is obtained.

If this circuit is operating without a filter coil, the current could be reduced by the variable grid voltage to only one half its maximum value, and then it would drop to zero due to its having control only during the first 90 electrical degrees. A smooth control from full load to light load can be secured by using a filter coil

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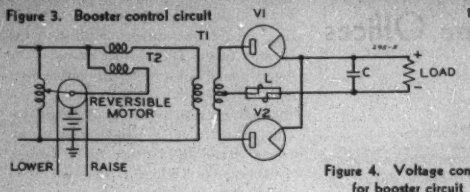

Figure 3. Booster control circuit

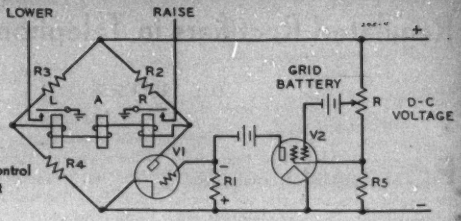

Figure 4. Voltage control for booster circuit

that has a high inductance with small currents, so that even though the tube fires near 90 degrees the current that flows is limited by the reactance of the coil. At full load its inductance is reduced by saturation of the iron to the value required for filtering. With conventional coil design where the no-load inductance can be made approximately five times the full-load inductance, the rectifier output current can be reduced by grid control to five per cent of the full-load value. When a telephone office load is applied to the battery, its external voltage decreases a fraction of a volt. This change is reflected over the potentiometer and grid battery to the grids to reduce the grid bias and increase the plate current of the tubes sufficiently to carry the office load.

With this circuit the battery voltage is held to a change of about one volt from no load to full load. This change in battery voltage is approximately the same for all values of battery voltage, as the grid must be varied about the same amount. Thus a better per cent regulation is obtained at the higher battery voltages. The regulating circuit will compensate for slight changes in the grid characteristics of the tubes. However, the large changes encountered in the case of mercury tubes make them unfit for this type of circuit. The mixture of mercury and argon has been found quite satisfactory when used in rectifiers covering a range of 24 to 60 volts. These tubes, however, have a low inverse-voltage rating and cannot be used in charging the higher-voltage storage batteries. The mercury tube has the necessary high inverse-voltage rating, so that a circuit was developed which has been called the phase-shift type of control; this enables the mercury tubes to be used, in spite of their changes of grid characteristic with temperature.

Phase-Shift Control

Figure 2 shows a schematic diagram of the phase-shift type[4] of control circuit. This circuit differs primarily from the magnitude circuit in that the grid voltage is an a-c voltage of a fixed magnitude, but its phase relation with respect to the a-c plate voltage is varied to control the output of the rectifier. When the grid voltage is out of phase with the plate voltage, the grid is negative all during the cycle that the plate is positive, so that the tube does not fire. As the grid voltage is shifted in a direction to be inphase with the plate voltage, the instantaneous grid voltage reaches a magnitude which is less negative than the critical value so that the tube will fire and deliver current for the remainder of that cycle. When the grid voltage is shifted to be practically inphase with the plate voltage, the tube fires at the beginning of the cycle and carries current during the remainder of that cycle. In this way the output current of the rectifier is controlled by shifting the phase from the out-of-phase to the inphase condition.

The grid voltage of varying phase is obtained from the phase-shift circuit which consists of a bridge circuit with two windings of the transformer furnishing two arms of the bridge, a capacitor the third, and the plate-cathode resistance of a vacuum tube the fourth. A transformer is connected across the galvanometer corners of the bridge which supplies the voltage to the grids of the thyratron tubes. When the plate-cathode resistance of the vacuum tube is at its minimum value, the grid voltage is nearly inphase with the plate voltage, the output current to the rectifier being maximum. When the vacuum tube is biased out (providing an infinite resistance) the grid voltage is practically out of phase with the plate voltage.

The plate-cathode resistance of the vacuum tube is controlled by the d-c bias applied to the tube. This varying grid bias of 2 to 20 volts is obtained from a vacuum-tube d-c amplifier circuit. When a telephone-office load is applied to the storage battery it decreases the battery voltage a fraction of a volt. This small voltage is amplified by the d-c vacuum-tube amplifier and applied to the phase-shift vacuum tube in a direction to shift the grid voltage more nearly into pbase and thus increase the output of the rectifier. In this way the storage-battery voltage is held to the regulated value. The accuracy of regulation depends on the amount of gain in the d-c amplifier circuit. This circuit has been built to provide regulation in the order of a few hundredths of a volt, but in most applications one per cent regulation is all that is required. The filter coil is not essential for the operation of this circuit, but a swinging choke whose inductance changes four to one will assist in regulation.

In a thyratron with an oxide-coated filament, operating filament temperature must be reached before output current can be drawn from the rectifier. An inexpensive way to prevent output current is to apply a large negative grid bias to the tubes, which biases them out even though the a-c voltage is applied to the plates. With the magnitude method, the grid circuit can be switched to the battery voltage and in the phase-shift circuit it is only necessary to open the resistance arm of the phase-shifting circuit. This switching can be done with a small telephone-type relay on all sizes of rectifiers. The time delay is provided by a conventional bimetallic-strip type of relay operating the telephone relay.

The cost of the thyratron tube, in sizes above ten amperes per tube, is large in comparison with the cost of the complete rectifier. High-gas-pressure rectifying tubes can be operated with the tube elements at high temperatures if the grid is omitted. This permits a two-element tube to be built at about one fifth the cost of the thyratron, thus making it practical to build low-voltage rectifiers in sizes of 30 to 100 amperes.

Booster Control

In order to regulate the output of a rectifier using two-element tubes, a circuit has been developed which has been called the booster type of control. Figure 3 shows a schematic diagram of this type of circuit. The output current of the tubes is controlled by changing the plate voltage applied to the tubes. The plate voltage is varied by means of a circuit consisting of a continuously tapped auto-transformer which changes the voltage applied to the primary of a booster transformer. When the continuously tapped

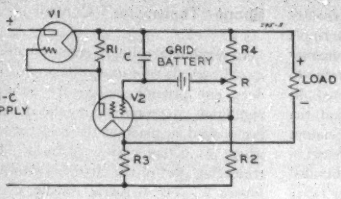

Figure 5 (left). Series-tube control with grid-battery voltage standard

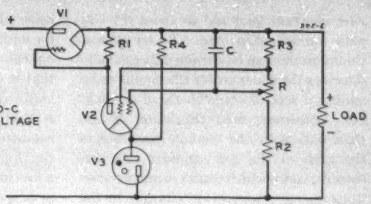

Figure 6 (right). Series-tube control with cold-cathode tube as voltage standard

autotransformer is at its zero end, no voltage is applied to the booster transformer and the ratio of the plate transformer is selected so that the rectifier delivers minimum current. The output current of the rectifier is increased by driving the continuously tapped autotransformer to its maximum boost position which raises the plate voltage until the rectifier delivers its maximum output current. The continuously tapped autotransformer is controlled by means of a small reversible motor so that closing the circuit of the "raise" lead will increase the rectifier output current and closing the circuit of the "lower" lead will drive the motor in the direction to decrease the rectifier output current. The disadvantage of this circuit is that a second transformer 40 per cent as big as the plate transformer is required in addition to the autotransformer. The advantage is that all of the equipment in this circuit operates at a high efficiency, and with the boost type of connection the no-load loss is small. Even the core loss of T_1 is reduced, since it operates at a lowered voltage at light loads. Light-load efficiency is important in telephone applications, as the rectifier must operate many hours at night with practically no load. The input power factor is the same as that of the unregulated tube-rectifier circuit and is not reduced materially by the control circuit.

Various combinations of this rectifier circuit are possible in that the plate voltage, in small sizes of rectifiers, may be connected directly to the continuously tapped autotransformer or the auxiliary transformer may be connected to buck the line voltage. This circuit can be applied to more than one phase with the appropriate tapped autotransformers, booster transformers, and plate transformer to control each phase.

A voltage controller to operate with the booster type of regulating circuit is shown in Figure 4. This circuit is to translate variations in the magnitude of the d-c voltage to be regulated into a raise and lower signal to the reversible motor in the rectifier. The circuit consists of a d-c amplifier to increase the small changes in the load voltage from a fraction of a volt to several volts. This amplified voltage is applied to the grid of a vacuum tube which constitutes one arm of a resistance bridge circuit. Across the galvanometer corners of the bridge are connected two polarized relays in series with a nonpolarized relay.

When the load voltage is at the correct value, the bridge is balanced and no voltage appears across the galvanometer corners of the bridge, so that all relays are released. The change in the load voltage will be reflected through the amplifier and bridge circuit in a direction to unbalance the bridge and cause either the R or L relay to operate, depending on which way the voltage changed, which in turn operates the motor in the rectifier circuit. Plate supply for the bridge tube V_1 is obtained from the d-c voltage being regulated, but a separate source of direct current is required for the plate of the amplifier tube V_2. This may be a battery or a small half-wave disk rectifier with a filter capacitor to provide 50 volts, one milliampere for the plate of V_2. The standard voltage can be either a grid battery or the negative resistance regulating circuit described below. The nonpolarized relay A operates on twice the current of the R and L relays, and is connected in series with them to give an indication when the regulated voltage is approximately twice the variation that causes the R and L relays to operate. In this way, an alarm may be provided to indicate when the regulated voltage goes out of the regulating range.

The accuracy of this control is entirely a function of the amount of d-c amplification provided by tube V_2. A single-tube amplifier operating with a load voltage of 24 or 48 volts will provide regulation in the order of 0.1 to 0.2 volt. An ordinary voltage relay may be used instead of this circuit, but its accuracy is limited by the difficulty of adjusting the span between the high and low contact of the relay to less than one volt. An additional advantage of this circuit over the voltage relay is that the span between the "lower" and "raise" signal is a va'ue fixed by the design of the circuit, but the average value of the regulated voltage may be shifted simply by adjusting the rheostat R.

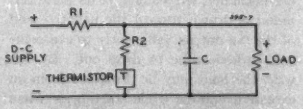

Figure 7. Shunt thermistor circuit

Series Tube Control

Where a small amount of closely regulated power is required, the series vacuum-tube type of regulated rectifier is used.[5] The conventional full-wave vacuum-tube rectifier and filter is used to provide about 100 volts more than the regulated value. A vacuum tube is connected in series with the output and its plate-cathode resistance acts as a dropping resistance. The amount of resistance it introduces into the circuit depends upon the magnitude of the grid voltage. To reduce the rectifier d-c voltage automatically to the regulated value the circuit shown in Figure 5 is used. The output voltage is applied by means of the voltage drop over the potentiometer R, which is opposed to a constant-voltage source such as a grid battery to the grid of V_2. If the grid-battery voltage is of the same magnitude as the load voltage, the maximum accuracy of regulation is obtained. However, with a screen grid or pentode tube sufficient amplification is obtained with lower-voltage grid batteries. By adding the R_3 resistance which is in series with the load current, its voltage drop is applied to the grid of V_2 to compensate for load changes.

With a circuit of this type, plus or minus ten per cent variations of d-c supply can be reduced to the order of 0.05 volt

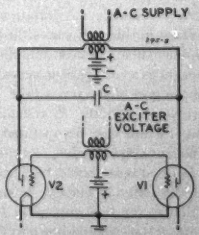

Figure 8. Fundamental inverter circuit

with constant load and to about 0.1 volt with variations in load. Better regulation than this can be obtained by carefully selecting the constants of the circuit or by adding a second stage to the d-c amplifier. However, with regulation of less than 0.05 volt, the contact potential in the grids of the d-c amplifier tube becomes a factor which causes random variations due to temperature changes in the cathode, produced mainly by variations in the heater voltage.

The circuit shown in Figure 6 is a variation of that shown in Figure 5 in that the voltage drop over a cold-cathode gas-filled tube is used as the standard for voltage regulation where accuracy of plus or minus one per cent to plus or minus three per cent is permissible. The arc drop of the tube V_3 is connected in the cathode circuit of the d-c amplifier circuit, and its grid voltage is picked off the potentiometer circuit, consisting of resistances R_3, R, and R_4, at a point which makes the grid of V_2 slightly negative with respect to its cathode. A variation in the load voltage in this way varies the grid of the amplifier tube V_2 whose amplified output appears as a voltage drop across R_1, to control the grid of the series tube V_1. It is desirable to add the R_4 resistance so that the V_3 tube can be operated at its most efficient current value, and the value of the R_1 resistance should be quite large so that the cathode current is small in proportion to the tube current in V_3.

In both of the circuits shown in Figures 5 and 6, feed-back filtering is obtained because the regulating circuit compensates for variations in voltage due to the ripple on the d-c supply in the same manner that it compensates for variations due to load. If the grid is not connected directly to the positive side of the load, the capacitor C should be added to conduct the ripple directly to the grid. Otherwise, a loss in ripple voltage would be obtained in proportion to the potentiometer ratio.

In this type of circuit the amplifier tube V_3 is usually of the heater type so that during starting, or in the event of a failure of the V_2 tube, the output voltage is unregulated and reaches a value approaching that of the d-c supply, except for the zero grid drop of the series tube V_1. This may be reduced by connecting a cold-cathode tube from the plate of V_2 to the potentiometer circuit at a voltage point with respect to the positive output terminal, which is slightly less than the breakdown voltage of the tube. Then with the circuit in normal condition, the tube will not pick up and will be an open circuit. If, however, the output voltage increases above the regulated value, the tube picks up and draws a current through the R_1 resistor which biases the series tube negative, reducing the output voltage. As soon as the V_3 tube is operating normally, the voltage of its plate terminal is drawn toward the negative end of the d-c output sufficiently to cause the cold-cathode tube to drop out. In this way, the load may be protected from an excessive voltage while starting or when trouble occurs in the amplifier tube.

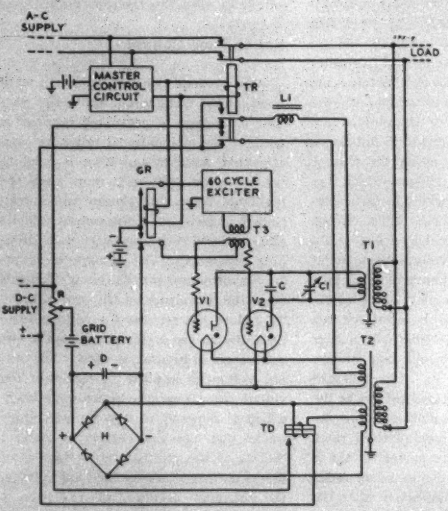

Figure 9. Combined rectifier–inverter circuit

Shunt-"Thermistor" Control

In regulated rectifiers where the use of a cold-cathode tube as a voltage standard does not provide sufficiently accurate regulation, a miniature regulated rectifier is used in place of the grid battery, where the higher cost is justified. The regulating part of the circuit is shown in Figure 7. The negative resistance is a "thermistor" made of a semiconductor. The value of R_3 is selected so that a change in d-c supply voltage causes a positive voltage drop in R_3 equal to the negative voltage drop in the thermistor with the net result that the voltage across the load is approximately constant. A resistance R_1 must be connected in series with the d-c supply to take up the variations in d-c supply voltage. This circuit, in general, is adaptable to voltages less than 100 volts and currents of a few milliamperes. Since most thermistors are sluggish in operation, a large capacitor C is connected across the circuit to smooth out rapid variations in d-c supply. The circuit is compensated for ambient temperature variations, as the resistance of thermistors is affected by temperature. This circuit has been used as a grid supply for amplifiers.

Rectifier–Inverter

With the increase in use of a-c voltages for filament and plate supply for repeaters, it became necessary to provide some means of providing power to operate these circuits when the commercial power supply had failed.[6] The electronic inverter using thyratron tubes provides a means to take energy from a storage battery and convert it into 60-cycle alternating current to keep the circuits functioning until the commercial power is restored. The elements of an electronic inverter are essentially the same as a rectifier, so that with the addition of a pilot source of 60 cycles and suitable switching means, one unit can serve as a regulated rectifier to float the storage battery normally, and during the time that the power has failed the circuit can take power from the battery and deliver 60-cycle power for use in the telephone office.

Figure 8 shows a schematic diagram of the fundamental inverter circuit. The battery is applied to the center tap of the plate transformer, and the grids of the tubes are held negative with a d-c bias sufficient to prevent their carrying current with the positive voltage applied to the plates by the battery. A 60-cycle excitation voltage is applied to the grid through the grid transformer. This ex-

citation voltage has a greater magnitude than the negative d-c bias. When the excitation voltage drives the tube grid toward zero until it reaches a value less than the critical grid voltage, the tube fires, passing current through one half of the plate transformer. When the other tube grid is fired in the same way it passes current in the opposite direction through the other half of the plate transformer. The charge on the capacitor which has accumulated while one tube is firing is connected across the opposite tube by virtue of the firing, which drives the plate negative to interrupt the plate current. The a-c excitation voltage is supplied by a mechanical vibrator of the type that is used in automobile radios or by a vacuum-tube oscillator.

A particularly useful type of power supply has been built which functions normally as a regulated rectifier, taking power from the a-c commercial supply and floating the telephone-office battery. The instant that the power fails, relays convert the circuit from rectifier to inverter operation, and energy is taken out of the storage battery and supplied to the telephone circuits in the form of 60-cycle alternating current.

The control circuit for the combined rectifier and inverter is shown in Figure 9. A master control circuit is provided to measure the a-c supply voltage continually so that when its magnitude reduces to less than 85 per cent of its rated value the *GR* and *TR* relays are operated. The *TR* relay disconnects the rectifier and load from the a-c supply circuit and also reverses the polarity of the d-c supply to the plate transformer. The *GR* relay starts the 60-cycle exciter and switches the grid circuit from the regulated rectifier circuit to the fixed negative bias. The circuit then draws power from the d-c supply and generates a 60-cycle voltage which supplies the load and also supplies its own filament voltage through transformer T_2. When the commercial a-c voltage is restored, the master control circuit releases the *GR* and *TR* relays to restore the equipment to the rectifier operation.

The control of the rectifier output current is by the magnitude method, which has been described. The regulating circuit consists of the potentiometer *R*, grid battery, capacitor *D* and "varistor" *H*.

Table I. Regulated Rectifiers Used in Telephone Offices

Rectifier Output		Type of Regulation	Rectifying Means
Volts	Amperes		
48	0.001	Shunt thermistor	Disk type
20	0.006	Shunt thermistor	Disk type
85	0.23	Series vacuum tube	Vacuum tube
120–130	0.10	Series vacuum tube	Vacuum tube
95–180	0.10	Series vacuum tube	Vacuum tube
150–180	0.15	Series vacuum tube	Vacuum tube
17–45	0.60	Magnitude	Thyratron
48–74	0.6	Magnitude	Thyratron
120–130	0.6	Magnitude	Thyratron
34–48	3	Magnitude	Thyratron
24–34	10	Magnitude	Thyratron
24	30	Booster	2-element tube
48	10	Magnitude	Thyratron
48	30	Booster	2-element tube
130	2	Phase shift	Thyratron
130	8	Phase shift	Thyratron
130	3	Magnitude	Thyratron
130	10	Phase shift	Thyratron

Application of load to the battery reduces its voltage, and this change in voltage is reflected to the grids of the thyratron tubes to reduce their negative bias, which increases the charging current of the rectifier to bring the voltage back to the regulated value. The varistor *H* and capacitor *D* provide a voltage which varies directly in proportion to the a-c line voltage. This change is introduced into the grid circuit to compensate for line voltage changes.

In order to use the same ratio in the plate transformer for both rectifier and inverter operation, it was necessary to have different methods of adjusting the output voltage of the rectifier and the inverter. The output voltage of the rectifier is adjusted by means of taps on the primary of the plate transformer T_1 for charging different numbers of cells in the storage battery. This tap is selected at the time of installation. The output voltage of the inverter is adjusted for various a-c loads by means of the commutating capacitor C_1. The above rectifier then can be adjusted for charging a 132- or 142-volt battery and to provide any a-c output voltage between 210 and 250 volts with current loads of 2 to 5 amperes.

The time required to convert this circuit from a rectifier to an inverter is limited primarily by the operating time of the relays. The master control circuit requires about one cycle to detect a low voltage, and the power relays require about two cycles to make the transfer. Therefore the minimum practical time of transfer is such that approximately three cycles is lost between the time the commercial power fails and alternating current is available from the inverter to carry the load. The transfer back to the commercial power supply will be less because the master control circuit has time to function while the load is carried by the inverter, and the release time of the relays is smaller than the operate time. The practical loss in load voltage is approximately two cycles.

Rectifier Sizes

Table I shows the voltage and current output, type of control of the rectifiers, and the rectifying means that have found widespread use in the Bell System.

The regulated rectifier finds its applications in telephone offices where constant voltage, independent of load and a-c line-voltage variations, is required to supply filament grid bias and plate voltage to telephone repeaters. Certain measuring circuits require a regulated rectifier to supply a stabilized voltage. Regulated rectifiers also find applications where constant voltage is of secondary importance but an automatic power plant is desired for maintaining storage batteries in a fully charged condition to be ready to supply the power for telephone offices if the a-c power fails. A further compensation of regulating the voltage is the increase in life obtained from storage batteries if they are not continually being charged and discharged but are fully floated.

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The Dielectric Strength and Life of Impregnated-Paper Insulation — III

J. B. WHITEHEAD
FELLOW AIEE

IMPREGNATED-paper insulation, as used in high-voltage power cables, is subject, during the ordinary processes of manufacture, transportation, installation, and operation, to a wide variety of conditions, nearly all of which militate against the conservation of the original inherent properties of the insulation. Among these conditions are bending and other mechanical stresses, expansion and contraction due to temperature changes, original variations in manufacturing processes of drying and evacuation, and so forth. As a consequence, the electrical characteristics of the insulation of high-voltage cables, as for example power factor, dielectric loss, dielectric strength, and stability, all fall noticeably below those of samples prepared in the laboratory and generally are not subject to all the disturbing conditions mentioned above.

The uncertainties arising in the presence of these disturbing conditions and the inability to determine their relative importance has meant that most of the improvement in the quality of cables in recent years has resulted from empirical development and experiments on the finished cable. Cable engineers have been slow to adopt the results of laboratory research on controlled specimens, except perhaps in the clear-cut results of studies of such fundamental matters as drying and evacuation as related to the impregnation process, the purification of oil and paper, and the like. They have feared the effect of a change in a known variable on those which are still unknown.

The experimental studies described in this series of papers fall definitely in the controlled laboratory class. Effort has been made to eliminate the influence of all those disturbing elements in cable insulation except a particular variable under study. For example, the specimens tested are assembled and impregnated, cable fashion on rigid smooth conductors; they suffer no mechanical deformation, they are tested at one temperature, and in particular, they contain no free gas. On the other hand, the type of specimen and mode of testing permit the study of many variables in paper, oil, and mode of assembly of the usual type of cable insulation.

It will be evident that great care and perhaps reserve should be exercised in applying the results of these studies to the design and construction of finished cables. From what has been said, for example, there is an important condition obtaining in the usual solid type of cable, namely, free gas and gaseous ionization, which has been carefully eliminated in the present tests. It is most important, therefore, in such cables to consider the possible influence of the variations shown in these experiments in a number of other variables, on the volume and extent of gaseous ionization. On the other hand, it appears that many of the results of the present studies should be immediately applicable to the so-called oil-filled type of cable in that both in finished cable and laboratory specimens the conditions are closely the same. Even in this case, however, it is necessary to bear in mind the difference between a relatively short-life test in the laboratory and the long-time performance of finished cable.

Cable engineers are nevertheless deeply interested in these research programs and the results therefrom. They have shown this interest by suggestion, discussion, and other cordial support and co-operation. The researches have been supported by grants from The Engineering Foundation with the sponsorship of the American Institute of Electrical Engineers and have enjoyed the hearty co-operation of an advisory committee of manufacturers' and utilities' engineers as appointed by the latter body.

Scope of the Work

The first paper of this series is devoted to a study of the influence of the density of the paper on dielectric strength and life, the outstanding result being a noticeable decrease of dielectric strength with increasing value of paper density. The second paper reports studies of the influence of the thickness of paper on dielectric strength. The earlier studies on density occasioned some surprise and were contrary to the expectations of a number of cable engineers. Consequently the present paper describes primarily further experiments on the influence of the density of the paper, particularly in the use of a different oil, and also studies on the influence of oil viscosity, all directed to a possible explanation of the unexpected results on paper density. In addition, results of a study of the influence of the width of oil channels between convolutions of paper tape on dielectric strength are described. In all these experiments a very sensitive and rapid method of circuit interruption has been used, resulting in the great majority of cases in partial failures without burning. Followed by careful examination, dissection, oil extraction, and magenta staining, this has resulted in a very intimate picture as to the probable causes of failure in each case.

The Test Specimens, the Paper, and the Oils

The Test Specimens

The specimens were wrapped on brass tubes 48 inches long and one inch in diameter. The central or measuring electrode was of lead foil 16.5 inches long. At each end it was overlapped by a lead foil guard electrode 9.5 inches long, separated therefrom by one layer of paper. Beyond the guards the specimen was equipped with narrow angle conical ends of impregnated paper designed for uniform stress distribution.

The Paper

The cellulose wood-pulp paper was supplied by a well-known manufacturer in four values of specific gravity 0.703, 0.896, 1.136, 1.144, all of approximately 0.005 inch in thickness, and here designated as papers *A*, *B*, *C*, and *D* in the order of increasing density. The paper tapes were in all cases one inch wide.

Certain observations were also made on a fifth grade of paper (*E*), of 0.004 inch in thickness remaining from foregoing studies and manufactured five years earlier.

The test specimens were made by wrapping the paper tapes on one-inch-diameter smooth brass tubes, normally with 33⅓ per cent and 66⅔ per cent

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overlay with a butt spacing of tapes of between $^1/_{64}$ inch and $^3/_{64}$ inch. The normal thickness of the insulation wall was 0.080 inch, that is, 16 layers of 0.005 inch paper. Studies of different channel widths up to $^1/_8$ inch were made with 0.005 inch *B* paper.

Nine identical specimens were constructed for each value of density, thickness of paper, for each value of channel width, or other variable studied. In a few cases the number of identical specimens tested was reduced to six.

For details as to the construction of the specimen, methods of test, experimental data, accuracy, and so forth, the earlier papers may be consulted.[1]

The Oils

Two high-grade insulating oils having commercial numbers 5,314 and 5,317 were each tested over the entire range of paper variables as described above. Number 5,314 is a thin oil as used in oil-filled cables. Its values of viscosity at 40 degrees, 60 degrees, and 100 degrees centigrade are 17, 8.2 and 3 centipoises respectively. Oil 5,317 is a heavier oil somewhat darker in color and prepared for use in solid-type cables. Its values of viscosity at 40 degrees, 60 degrees, and 100 degrees are 480, 120, 18.3 centipoises respectively.

The specimens were impregnated in groups of three, normally at 60 degrees centigrade. In certain studies of the influence of viscosity on impregnation, the impregnating temperature of 5,314 was reduced to 40 degrees and that of 5,317 raised to 100 degrees, these temperatures giving the same value of viscosity for the two oils.

Breakdown and Stability Tests

The accelerated step-up life tests started at 400 volts per mil. The voltage was increased by 3.12 per cent every four hours, thus giving a geometric increase to 700 volts per mil in three days. The continuous application of voltage was interrupted at intervals (usually every four hours) for tests of power factor, capacitance, and internal gaseous ionization.[2] In this program the average life of a specimen was from two to five days. It has been assumed that this brief duration eliminates the influence of chemical change. Long experience has shown that there is no free gas in these specimens. Consequently the results appear to isolate definitely the influence of each of the several variables studied, that is, paper density, paper thickness, oil viscosity, and so forth. The design of the specimen and close attention to uniformity of construction have ensured that the failures have occurred almost invariably under the central electrode of the specimen.

Results of Tests

Density of Paper

The results of the tests on four values of paper density using 5,314 oil have been published in an earlier paper.[3] For convenience some of them are reproduced in Figures 1 and 2. In the same figures will be found the results of later studies on the same papers as impregnated with 5,317 oil, and under the same conditions as to impregnation, test program, degree of accuracy, and so forth.

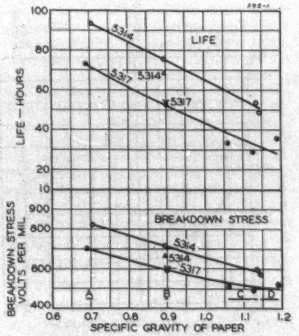

Figure 1. Stability of oil-impregnated-paper insulation—life and breakdown stress

Impregnation at a pressure of 2.0 millimeters of mercury
Δ—40 degrees centigrade
x—100 degrees centigrade
All others—60 degrees centigrade

Two noteworthy features are indicated:

1. The decrease of dielectric strength and life with increasing paper density, already reported for 5,314 oil, is also found to obtain with close parallelism for 5,317 oil.

2. Values of dielectric strength and of life using 5,317 are uniformly lower than those for 5,314.

The impregnating oil content is somewhat higher for 5,314, particularly at the low values of paper density. The power factor for 5,314 is also higher. The trend of these curves has been discussed in the earlier papers.

Paper Thickness

The studies of the influence of paper thickness with 5,314 oil only have been reported in an earlier paper.[4] Figure 3 is reproduced therefrom. It will be noted that there is a pronounced and uniform decrease of breakdown strength with increasing thickness of paper ($21^1/_2$ per cent decrease from 0.003 inch to 0.008 inch thickness).

Saturation Studies

For each group of tests the percentage of oil content by volume was determined for one or more specimens. Thus in Figure 2 the decrease of percentage of oil with increasing paper density is readily noted. It is also noticed that specimens impregnated with 5,314 oil contain a higher percentage of oil, other things being equal, and that this is accompanied by higher dielectric strength. The same parallelism has been observed in other tests. In order to determine whether viscosity of the oil had any bearing on these differences, six specimens of *B* paper were impregnated with 5,314 oil at 40 degrees, and six others with 5,317 oil at 100 degrees, the viscosities of the two oils having the same value at these temperatures. All twelve specimens were subjected to life test at 40 degrees centigrade, in accordance with the standard program.

Results of these comparative studies are indicated as single points giving the average values in Figures 1 and 2. The

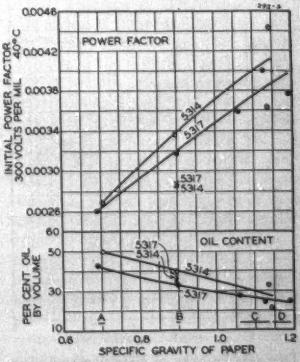

Figure 2. Stability of oil-impregnated-paper insulation—power factor and oil content

Impregnation at a pressure of 2.0 millimeters of mercury
Δ—40 degrees centigrade
x—100 degrees centigrade
All others—60 degrees centigrade

order of accuracy is about the same as that in the paper-density studies (plus or minus deviation five to ten per cent). It will be noticed that the change of viscosity of 5,317 oil results in no appreciable change in either dielectric strength or life, notwithstanding a rather wide variation

in the value of viscosity (480–120 centipoises). On the other hand, impregnation with 5,314 oil with a considerably smaller variation of viscosity results in a slight lowering of both dielectric strength and life, although the values are still substantially higher than those for 5,317.

As to oil content, in the case of number 5,317, large decrease in viscosity between 60 degrees and 100 degrees results in the small increase of oil content of from 33 per cent to 37 per cent. In the case of 5,314 oil the increase of viscosity between 60 degrees and 40 degrees in these comparative studies results in a reduction from 40 per cent to 34 per cent. When the viscosities are the same, the oil content and power factor are about the same.

Width of Channel

The influence of the width of channel on breakdown strength and accelerated life was studied between the limits of a close butt joint and a maximum channel width of $^1/_8$ inch, observations being taken at one intermediate thickness, $^3/_{64}$ inch. Observations were also made on six specimens having a $^1/_{64}$-inch overlap, for one of the oils. Otherwise nine specimens were tested at each channel width and for each of the two oils, 5,314 and 5,317.

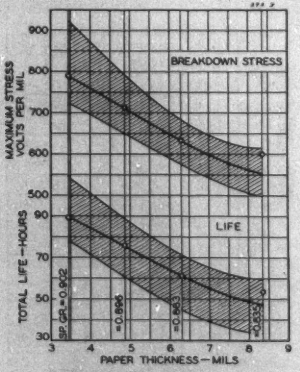

Figure 3. Stability of oil-impregnated-paper insulation—breakdown stress and life

The results of these studies are plotted in Figure 4, in which the average spread of the nine specimens represented by each point is indicated in vertical lines.

It will be noted that the decrease of dielectric strength with increasing width of oil channel is practically linear for oil 5,314, the percentage decrease from a close butt joint to a channel width of $^1/_8$ inch being 9.5 per cent. A similar over-all decrease is seen for oil 5,317, although the rate of decrease with channel width is less regular. The over-all decrease in this case is roughly six per cent. No great accuracy may be claimed for numerical values in these results, principally because it is difficult to maintain a uniform channel width of low value. Thus in the close butt experiments, the results on two specimens have been omitted, because on dissection it was found that the joints between tapes were slightly open in the region of failure. The closest butt joint that can be wound seems to have here and there a slight opening. With this in mind a set of specimens was wound with a $^1/_{64}$-inch overlap,

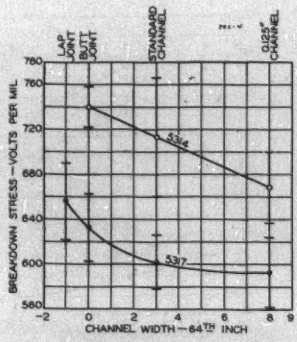

Figure 4. Stability of oil-impregnated-paper insulation—breakdown stress versus channel width

and it may be seen from the curve for oil 5,317 that this resulted in a still further slight increase of dielectric strength.

It is to be noted that the higher dielectric strength of oil 5,314 over 5,317 noted in the other experiments, appears also in the experiments on channel width.

Types of Failure

Initial and Partial Failures

An early method of interrupting the circuit following breakdown of the specimens, using a very light fuse in the primary circuit of the testing transformer, resulted uniformly in through failures with considerable burning. Later, use was made of a thyratron tube, operated from the voltage over a resistance in series with the connection of the low-voltage electrode to ground, and operating a fast-moving relay and circuit breaker in the primary circuit. This resulted in early interruption of failure and indeed enabled us to remove and examine a great many specimens in which partial failures only had occurred. These partial failures consisted of the burning, or break through, or other evidence of trouble, in from one layer of paper or channel of oil, to an increased number of layers up to but short of the full insulation wall. The amount of burning in a failed specimen of this type is very greatly reduced, and a much better idea of the origin, causes, and succeeding progress of the failure has been obtained.

The failures may be roughly divided into four groups based on careful dissection followed in many cases by oil extraction and staining with magenta:

A. Through radial failures.

B. Partial failures involving one half of the total thickness of the insulating wall or less, and all terminating on the high-voltage conductor, or on the outer lead sheath.

C. Partial failures within the insulating wall, but not reaching either conductor or sheath.

D. Failures with no outward evidence of burning, but with subsequent evidence of wax formation.

Out of a total of 117 specimens tested, 46 had complete through failures and 66 had partial failures of one type or another.

Class A—Through Radial Failures. In these cases the burning is greater than in the partial failures, but in general the evidence is that there is little departure from an approximately straight radial failure ending in an oil channel near the outer layers and the first adjacent layers. Tree patterns and tracking are often evident, but only to the extent of reaching one adjacent oil channel. Puncturing through the tape of four consecutive layers was not uncommon.

Class B—Partial Failures Ending on Inner or on Outer Conductor. The characteristic of most of these failures is an area of blackened or burned oil film, never greater than one inch in diameter, towards the center of the insulating wall. Beyond the burned spot, evidence of trouble diminishes rapidly within one or two layers, then disappears. In the other direction burning also decreases, the puncture taking the form of short lengths of blackened oil in the channels and puncture through tapes, becoming smaller and cleaner towards the electrodes. The first, second, or third oil channel from the high-voltage conductor is usually involved. An exceptional case in this group consisted of four tiny punctures of four outside layers, originating in the oil adjacent to a corner of reinforcing paper at the end of the specimen and with no evidence of burning.

Of a total of 66 partial failures, 11 terminated on the outer electrode and 49 on the inner electrode. In one case there was a partial failure to each electrode, the two being well separated longitudinally, and apparently not related.

Class C—Partial Failures Not Reaching Either Electrode. Only three failures of this type were noticed, but they were quite definite. They were characterized by iso-

lated black regions in an oil channel. Two were within four layers of an electrode. In one case the trouble was confined to only two layers.

In addition to these clearly marked local failures, there were ten cases in which this type of trouble was found to be coexistent with a failure either "through" or "partial" ending on an electrode, although definitely separated from it.

Class D—Failures With No Outward Evidence of Burning. In two cases first examination of the specimen failed to reveal any trouble other than a slight smell of burned oil. After subsequent oil extraction and staining with magenta dye, there was evidence in each case of initial wax formation at various places.

In considering these results, it should be borne in mind that in our specimens the insulation wall was relatively thin (0.08 inch), and the diameter of the smooth high-voltage conductor was relatively large (one inch). The excess of stress at the conductor surface over that at the outer electrode is of the order of 16 per cent, which is not much greater than the values of the average spread of our experimental breakdown results; thus partial failures originating on the outer electrode may be due to normal variations in the paper or oil. The smooth high-voltage conductor is perhaps an advantage in that it eliminates the common type of oil pocket in stranded conductors and confines the experimental results more definitely to the impregnated wall.

Throughout the careful examinations of the failed specimens, constant evidence has been found that the initial trouble arises in an oil space. In the cases of partial failures, either the first or the second oil channel was always involved. In all cases involving one, two, or three layers only, punctures were rarely found, the trouble being of the nature of oil blackening and surface tracking. Also in all cases without exception it was found that the oil in the channel next to the high-voltage conductor was more or less blackened, in many cases the blackening being limited to the edges of the paper and revealed by fine black lines on the polished conductor.

Discussion

It is believed that the outstanding results of this and the foregoing papers may be explained qualitatively in terms of the characteristics of the impregnating oil.

All refined degassed insulating oils apparently have the following characteristics in greater or less degree:

(*a*). A relatively low long-time conductivity, that is, as measured after a long application of continuous electric stress. This conductivity is partly electronic, but largely due to an inherent electrolytic dissociation arising in the complex molecular structure.

(*b*). An initial or short-time conductivity persisting for, say from one-tenth to one second, which may be many times as great as the short-time conductivity. This conductivity is due to an accumulation of relatively large and heavy ions or clusters of neutral molecules about a central ion. It is the motion of these large ions back and forth under alternating stress which causes the greater part of the dielectric loss in such oils.

(*c*). Both types of conductivity are increased by contact with paper and metals, due to added electrolytic impurities, and also to increased electrolytic dissociation.

(*d*). Application of continuous stress causes the large heavy ions to move to the electrodes or limits of an oil space, where, owing to their envelopes of neutral molecules, not all of them are discharged, and space charges accumulate close to the electrodes or other limiting surfaces, for example, paper tapes. Under alternating stress a similar action goes on resulting in maximum space charge accumulations at the crest of each half cycle. Studies of the mobility of these ions indicate that at 60 cycles there is sufficient time during a half cycle for some at least of these ions to pass completely across the oil channels occurring between paper tapes in impregnated-paper cable insulation.

The mass of evidence from the failures studied in this series of papers is that failure begins in an oil channel between paper tapes and probably at the contact surface between paper and oil. The failure is caused by a layer of high stress between the paper and a space charge layer immediately adjacent. Witness for example the spiral marking on the high-voltage conductor immediately under the edges of the paper tapes and over the full length of the specimen; also the isolated cases of partial failure in which the only evidence of failure is blackening in the channels, with carbonized channels through paper tapes spreading therefrom.

The ultimate cause of failure is a stress sufficiently high to ionize a molecule with the liberation of gas. The tiny bubble of gas may be reabsorbed before the next voltage crest in which case increasing carbonization may result before final failure. With further increase of stress, however, the gas bubble becomes larger, continues through the cycle, and is the seat of gaseous ionization. This latter attacks the adjacent paper much more aggressively, leading ultimately to puncture, to the extension of the oil breakdown in the next oil film, and to surface spreading to the adjacent oil channel of the next layer.

Failures here described, in outward appearance are often similar to those described by Robinson.[6] However, there is much indication in this work that the "coring" in the paper tapes occurs at the end rather than at the beginning of the process of failure. Coring has been noticed frequently at both conductor and sheath, but in these cases the complete absence of burning, as compared with conditions in the oil channels of deeper lying layers indicates strongly that the initial trouble originates in the channels then extending to puncture of the paper by the coring process. In our case we picture the oil as breaking down with the liberation of gas, subsequent gaseous ionization attacking the paper wall, perhaps in the manner suggested by Robinson. However, Robinson postulates a free gas bubble originally present near the high-voltage conductor, gaseous ionization in this bubble, and coring as the first stage of failure in the insulation wall itself. We believe our specimens to be originally entirely free of such gas bubbles and that the first gas that appears is due to oil failures. We do not find that coring is limited to the inside layers, due to the small difference in radial stress between outer and inner layers in our specimen. However, in the cases discussed by Robinson the higher stresses on the inside layers would tend to give first oil failures and subsequent coring in those layers.

The decrease of dielectric strength with increasing density of the paper tapes has already been ascribed to the increasing value of the stress in the oil channels due to the increasing value of dielectric constant of the impregnated paper. Approximate computation of the breakdown stress in the oil indicates a slight decrease in the critical stress with increasing paper density.[3] It is suggested that this is explained by the fact that the oil in contact with papers of increasing density takes on a greater number of adsorbed ions from the paper. There is a resulting increase in the density of the space charge layers, and an increase in stress between this layer and the adjacent surface. Thus the critical or breakdown stress in the oil is reached at a lower voltage or lower average stress.

Some cable engineers have been loth to accept this evidence that the dielectric strength of impregnated paper decreases with increasing paper density. It is stated that in manufacture, cables containing high-density paper give a higher dielectric strength than those using paper of a lower density. In one case it is stated that it has certain other advantageous physical properties. There are, however, no published data clearly showing these advantages of high-density paper in comparative life tests under sustained stress.

One possible explanation is that there

may be a difference in behavior under impulse or short-time tests and under sustained voltage tests. Here too experimental data is very meager. Del Mar and Works have recently presented data indicating that under short-time tests for certain values of overlap of paper tape, the breakdown strength of high-density paper may rise above that of low-density paper. However, as emphasized elsewhere in this paper, a time element undoubtedly is present in failures under sustained high stress. It is possible, therefore, that under impulse or short-time tests the inherent high dielectric strength of the high-density paper might play a more important part than the delayed breakdown of oil in the oil channels, in which the stress is much higher than the over-all average stress, due to the difference in the dielectric constants of the impregnated paper and the oil in the channels.

A pronounced decrease in dielectric strength with increasing paper thickness has been found.[4] This result may be attributed to the well-known fact that the breakdown strength of thin oil films decreases with increasing thickness. However, in this case also, approximate computations of the values of stress in the oil films at breakdown decrease with increasing thickness, again giving a first indication that the breakdown stress of the oil does not have a constant value. The same explanation may be offered here, namely, that with increasing paper and channel thickness, more ions are present in the oil film, greater values of space charge accumulate, and a critical breakdown strength of the oil is reached at a lower value of over-all stress.

Conclusions

1. Laboratory studies in accelerated life tests of the influence of the density of the paper on the breakdown strength of impregnated-paper insulation have been continued. When impregnated with a heavier oil, as used in solid-type cables, there is a marked decrease of dielectric strength with increasing paper density. Results are closely similar to those already found using a thin oil as impregnant.

2. Raising the viscosity of the thin oil and lowering the viscosity of the heavy oil so that both have the same value during impregnation has little effect on the breakdown strength. Specimens impregnated with the heavy oil show no change in behavior. Raising the viscosity of the thin oil results in a slightly lower dielectric strength. When the two oils have the same viscosity, the values of power factor and of oil content are approximately the same.

3. The dielectric strength of impregnated paper decreases with increasing oil-channel width between successive convolutions of tape. When the thin oil is used the decrease is about 9 per cent; when the heavy oil is used, the decrease is about 6½ per cent, as the channel width increases from zero (close butt joint) to ⅛ inch.

4. In all the foregoing experiments the dielectric strength and stability when using the thin oil as impregnant were noticeably higher than when using the heavy oil.

5. Close examination of all failures leads to the conclusion that in the accelerated life or stability tests lasting two days or more, failure always begins in an oil space.

6. Qualitative explanations are offered for results in this and two preceding papers of this series.

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